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FLATS AND PHYSIOGRAPHIC PROCESSES IN THE UPPER KUSKOKWIM RIVER REGION, ALASKA

With suggestions for the origin of certain mucks, examination of the nature of the local plant associations, a discussion of the implications as to periglacial climates.

By

William H. Drury, Jr.

UNIVERSITY OF MISSOURI
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JRE 1. THE UPPER KUSKOKWIM RIVER REGION. Place names mentioned in the text are included. distribution of bogs is shown using standard marsh symbol, and the bed-rock hills using a ed tone. The inset map of Alaska shows the location of the area of study outlined in black he distribution of generally forested regions. (Forest distribution taken from Hopkins and)os, 1951).

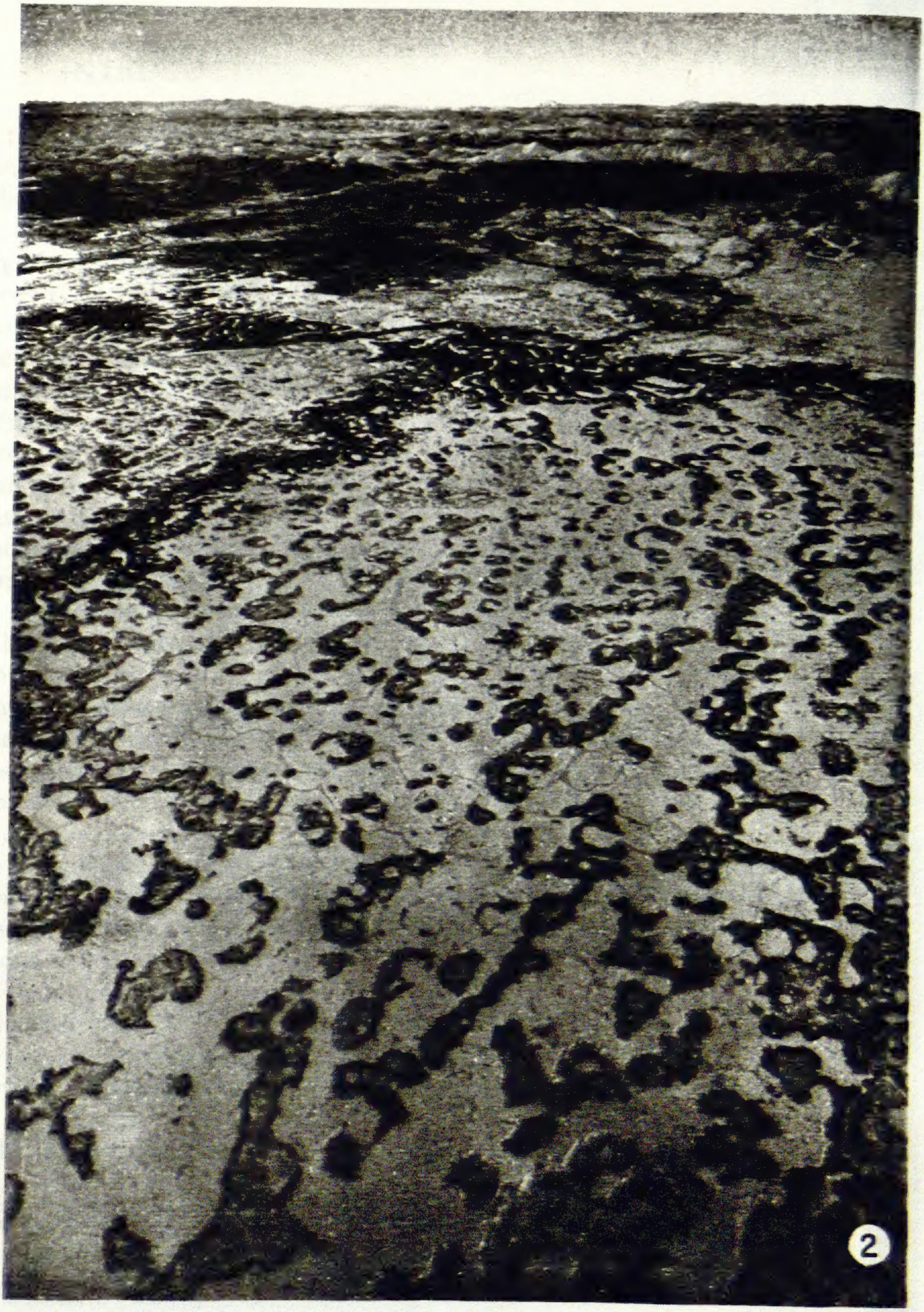

FIGURE 2. AERIAL PHOTOGRAPH FROM 20,000 FEET LOOKING NORTHWEST ACROSS THE NIXO FORK FLATS. This illustrates a lowland from which the forest has been nearly eliminate by bogs. Downslope movement of water is responsible for the orientation of the bogs an the remnant islands of Black Spruce. White Spruce forests on the well-drained levees o the main stream appear as the very dark pattern in the background. Black Spruce appear as the middle of tone of gray. The photograph was taken in the winter and snow cove makes the bogs appear white. (Photograph courtesy of the U.S. Army Air Forces).

INTRODUCTION

The extensive treeless bogs which cover the broad alluvial lowlands of the interior and southern coastal regions of Alaska are of a far northern type which occurs all across Eurasia and North America [1]. These bogs are characterized by their great size, by their large areas flooded by standing water, by their anastomosing pattern in which they surround islands and peninsulas of forest, as well as by their surface patterns of sinuous bog ridges and regularly spaced clumps of trees. In addition, in Alaska the bogs are actively undermining and engulfing the forests of the lowlands by processes active at their banks. An isolated bog area in the Upper Kuskokwim River Region occupies an area of 250 square miles (Figures 1 and 2), and the bog areas along the Tanana River south of Fairbanks occupy several thousand square miles. Continuous quaking bogs have been seen in Alaska as long as 15 miles and as wide as 5 miles. The bogs and the patchy forest areas in them are locally called "Flats". These flats are the *Aapasuo* of Finland. Their surface patterns of nets and festoons of bog ridges put them in the category of the *Strangmoor* of the Germans.

As this indicates, similar areas have been studied in Europe and a number of separate terminologies have been developed. An attempt is made here to compare and equate these terms and for this reason the reader is asked to show patience with numerous cross references in some parts of this paper. Because the text is in English, equivalents have been supplied, such as bog ridge and bog hollow. These are not intended to be new terms and are entirely synonymous with German, Swedish or Finnish words, as pointed out in the Glossary.

Early studies in Europe, such as that of Cajander (1913), described the distribution and vegetation of the three major types of bog in Scandinavia. Recent studies have concentrated almost entirely upon the raised bogs or mosses (*Hochmoors*) of Central Scandinavia and the shores of the Baltic Sea, and have investigated

---

1) I have seen them in the Yukon and Tanana lowlands, in the Cook Inlet and Bristol Bay areas of Alaska, in Northeast Manitoba, and in Ungava. They have been reported in Labrador (Wenner, 1947, p. 201); in Sweden and Finland (Cajander, 1913, Taf. 9, 10; Auer, 1920, Taf. 1-7; Troll, 1944, p. 639-640; Sjörs, 1948, p. 189 etc.) and in northern Russia and western Siberia (Troll, 1944, p. 640; Katz, 1926, p. 184 etc.).

the physiology of individual plants or plant groupings. They have been concerned with the growth and formation of peat, and geological studies have been carried out simultaneously. In America, Shaler in 1890 described bogs colonizing a pond and invading the wet soil of a wet woodland. Since then many authors have described bogs in temperate North America as phenomena of special conditions of restricted distribution, such as undrained topographic depressions. Furthermore, these studies are founded on acceptance of successional sequences by which open water is colonized, filled with plant remains and transformed into a forested lowland. The concept of unidirectional succession and and progressive development to a stable equilibrium as a generalization of vegetation process is inherited from the work of F. E. Clements. Earlier workers did not visualize the succession as unidirectional nor the mesophytic equilibrium as final or climactic.

Most bog studies, especially those of the New World, have considered either plants or geology while slighting or not understanding the limitations of the other processes. A few men, such as V. Auer, have studied the intimate integration of physiographic processes with the growth of groups of plants.

There are processes in the river-deposited silts and in the bogs studied in this paper tending to build and compact a frozen soil of mixed silt and peat called Muck in Alaska[2]. On this soil a muskeg forest grows. At the same time processes lead to the destruction of the lowland forests and invasion by bogs. Creation and destruction of forests and bogs is repeated and phases of bog and forest primacy move across the lowland.

Bogs of regional extent, which engulf the forests and are seen to replace them in a successional sequence, cannot be forced into the frame of reference set up in temperate regions. The correlation of bog types with ages of the floodplain and the particular phenomenon of the advance of bog margins by thawing and undermining the forest show the close relation of these bogs to geological processes. The patterns of vegetation, of islands, and of networks of ridges show that physical forces are of fundamental importance in the bog surface vegetation. These observations lead

---

2) Muck is defined by geologists as a mixture of silt and finely divided organic material. To the Alaskan placer-miners muck is any fine-grained material overlying the gold-bearing gravels. In Interior Alaska the mucks are usually frozen.

to the conclusion that these bogs must be studied as a combined phenomenon of geological and vegetational processes acting in concert and not as an isolated and peculiar vegetational feature independent of its surroundings while proceeding to its own predetermined goal. Geological processes are evidently the key to the description of the bogs, and beyond that to the understanding of their formation and development. The contribution of this paper is maintaining the integration of these processes.

In the course of these studies I have reached a number of conclusions which may be of some general application. It has become evident that geological and botanical processes involved in the formation of these bogs alter the sequence of sediments and modify alluvial deposits of different ages and histories, obliterating their differences. An understanding of these processes will contribute to the knowledge of the history of the Pleistocene and Recent epochs by application to stratigraphy and to pollen analysis, and by the evidence these contribute to knowledge of the climates of the past. Furthermore, the change of vegetation in which regional bogs supplant forested lowland areas by botanical as well as geological processes is a serious argument against the application of theories of regional or climatic climax vegetation to the vegetation of these areas. The study of this change is a contribution to the understanding of what processes are actually involved in vegetational successions.

The processes studied here contribute further evidence supporting the importance of soil instability and the effects of frost action on the patterns of vegetation and the containing action of the carpet of plants. Whereas nearly all studies so far published (such as: Crampton, 1912; Polunin, 1934—35; Hopkins and Sigafoos, 1951; Raup, 1951) have been concerned with physiographic effects of frost action on uplands, these investigations are a study of the processes active in alluvial lowlands.

Field work in the bogs totalling just less than a month was completed during the summers of 1949 and 1950 coincident with other duties in the area. The opportunity and laboratory and herbarium facilities for three years study of field data were supplied by the Society of Fellows of Harvard University.

Debt for ideas obtained during discussions in the progress of the field work is acknowledged to William S. Benninghoff, Jr., Robert F. Black, Jr., George S. Corchary, Arthur T. Fernald

and William C. Steere. Debt for critical reviews is acknowledged to them and to John Goodlett, David M. Hopkins, Ernest H. Muller, Troy Péwé, Hugh M. Raup, Robert S. Sigafoos and John R. Williams.

DESCRIPTION OF THE AREA

Geography

The area studied (Figure 1) is in the Upper Kuskokwim River Region which lies between 62° and 63° 30′ north latitude and between 154° and 156° west longitude. This is in the region of discontinuous permafrost (Black, 1950) and within the limits of the boreal needle-leaved forest. The Kuskokwim River valley forms a lowland 50 miles wide trending northeast to southwest across the map area. The Alaska Range, rugged "young" mountains (in the Davis 1899 and 1909 sense), rising to peaks of 10,000 feet lies across the southeast corner. The "old" hills of the Kuskokwim Mountains enclose the basin on the west, northwest and north.

Both acidic and basic rocks, both crystalline and sedimentary are included in the structure of the two ranges. The oldest rocks are Paleozoic in age and occur in three areas: (1) the northern flank of the Alaska Range in the Farewell district; (2) the Nixon Fork district; and (3) along the Kuskokwim River from Medfra to McGrath and south. Limestone is the predominant rock type in the first two districts, and shale along the Kuskokwim. Datings are discussed by Spurr (1898), Brooks (1911), Brown (1926), and Smith (1939).

Rocks of Cretaceous age underlie the upland areas to the west. These are mostly interbedded graywackes and shales which have been folded in the area along the Kuskokwim River. Tertiary intrusives, stocks and smaller igneous bodies, are scattered throughout the area (Mertie and Harrington, 1924; Brown, 1926; Mertie, 1936).

Glaciers flowing from the snowfields of the Alaska Range have in the past extended northwestward as much as 20 miles beyond the front of the Alaska Range. Outwash deposits from the rivers in their valleys form a piedmont surface sloping gently to the northwest which is crossed by the South Fork (Echeatnu

in Hultén, 1941), the Middle Fork, Salmon River, Windy Fork, and the Big River (West Fork in Péwé, 1953, pl. 1). These tributaries change from braided to meandering streams as they cross from the piedmont to the valley lowlands and there join with the North Fork to form the major river, the Kuskokwim. The Kuskokwim flows to the southwest between high alluvial terraces 60—100 feet above the river level, then plunges into and across the Kuskokwim Mountains from which it emerges to flow north of the Killbuck Mountains, and into the Bering Sea south of the Yukon River.

Deep fine-grained alluvium, modified on the valley sides by depositional-slope-deposits, underlies the floodplain of the Kuskokwim, the reëntrant valleys in the Kuskokwim Mountains, such as that of the Takotna and Nixon Fork Rivers, and the lower one-third to one-half of the piedmont slope from the Alaska Range. The alluvium extends up minor streams onto the lower parts of hill-slopes and terraces.

The town of McGrath, altitude 550 feet, (Figure 1) is at the junction of the Takotna River with the Kuskokwim and is a transhipment site for supplies to the gold mines in the Kuskokwim Mountains. The floodplain of the Kuskokwim is about 4 miles wide there, and the surface of the floodplain at the town is about 8 feet above the average summer river level. The main river averages 1,000 feet across and the zone of active meanders is about 2 miles wide. Most of the active meander belt shows evidence of regular flooding during spring "break-up" of the river ice. Perennially frozen ground (Permafrost) is widespread in fine-grained sediments of the depositional slopes and alluvial lowlands. Its distribution coincides with that of Black Spruce forests.

Climate

The lowlands of the Upper Kuskokwim River Region (climatic data according to Hopp, 1951) have cold and dry winters and and warm and wet summers. Maximum precipitation is in July, August, and September. The daily summer maximum temperatures average in the low seventies and the frost-free period is about 120 days. Annual cloudiness averages slightly over seven-tenths. According to Köppen's (1931) climatic classification, three times as much rain falls as is needed to make the McGrath climate

(mean annual temperature 25.5° F.) "moist".

The cold dry winters relate the climate to continental types. but the vegetation shows a definite maritime character (forests and bogs). Winter dormancy must allow the plants of this area to resist extremes of winter temperatures, so that it is the conditions of the growing season which control the type of vegetation present. The growing season in bogs probably only approximates the frost-free period, given as 120 days, because the bogs have been found to be frozen on June 9—12, 1950, which is more than three weeks after the last killing frost reported at McGrath (May 18). Frost-nipped plants were seen in bogs a month before the first killing frost reported at McGrath in the middle of September.

Vegetation

About 75% of the Upper Kuskokwim River Region is forested. In the lowlands and on the slopes of the hills, well-drained and sunny sites (15% of the area) are forested with a White Spruce mixed forest [3], but by far the greatest proportion, including most of the lowlands, the depositional slopes and all the poorly drained gentle slopes (60% of the area), is forested with Black Spruce (*Picea mariana*).

Ten percent of the area is occupied by large bog areas which spot the older parts of the valley bottoms where surface and subsurface water has stagnated. Bog areas are indicated with standard swamp symbol in Figure 1. The hilltops of the Kuskokwim Mountains, the Alaska Range and the upper third of the piedmont slope northwest of the Alaska Range (15% of the area) are beyond the limit of closed forest.

On the well-drained sites on the older parts of the floodplain and on warm hillslopes, Birch is prominent in the mixed forest. but Birch does not extend above 1,000 feet. Thus, on the depositing slopes of meandering streams and along the braided streams in the Alaska Range, the forest is largely of White Spruce and Balsam Poplar.

3) White Spruce-mixed forest refers to forests containing deciduous trees as well as White Spruce (*Picea glauca*). On upland surfaces the deciduous trees are aspen (*Populus tremuloides*) or white Birch (*Betula papyrifera*, usually variety *humilis*). On floodplain surfaces the deciduous trees are Balsam Poplar (*Populus balsamifera*) and White Birch (*Betula papyrifera* usually variety *kenaica*).

The dry ridges of the extensive areas of sand dunes or erosional remnants on the high terraces along the Kuskokwim River are covered with a lichen-floored open forest of Black Spruce and Aspen with a Birch (especially *Betula papyrifera* var. *humilis*) and White Spruce admixture [4]. The low places on these terraces are Black Spruce muskegs through which flow sphagnum-clogged streams. Aspen groves line small pools.

The low hill slopes and valley bottoms are forested with Black Spruce and bogs are scattered through this forest in the lowlands. These vegetation types are discussed in detail in the following chapters.

Tree-line is at about 1,000 feet on north slopes and at 1800—2100 on south slopes. At tree-line on the piedmont slope is a tundra-forest (Berg, 1950), of Black Spruce, White Spruce or Larch with a dense low-brush growth of heaths and dwarf birch and a thick moss mat. Immediately above the limit of trees the ground is covered with a carpet of mosses, lichens and low brush identical with the understory of the wet spruce forests. This mesophytic tundra vegetation is modified according to exposure and drainage, and special expressions of it occupy large areas. For example, on the slopes of the gravel outwash there is a development of cotton-grass tussocks, tussock-tundra (Hopkins and Sigafoos, 1950), (known locally as "nigger-heads") covering as large an area as that occupied by the mesophytic tundra.

Above 2,500—3,000 feet and on well-drained ridges the vegetation consists of a more or less interrupted carpet of prostrate shrubs and mat plants such as willows, heaths and Mountain Avens (*Dryas*), with some mosses and many lichens [5].

---

4) It seems to correspond to the Siberian *taiga* forest as described by a native of that part of the U.S.S.R., and resembles Raup's (1946) park-like spruce forest northeast of Lake Athabasca.

5) The moss-lichen-low brush vegetation immediately beyond treeline is characteristic of the more mesophytic sites of the treeless areas all across the north. It is the low-lying tundra as Middendorf (1864) described it in Siberia, and the wet tundra as Sigafoos (1951) described it in Seward Peninsula. Polunin (1948) has documented the occurrence of this type of vegetation across the eastern Arctic. It resembles the "Sphagnetum" and "Blanket Bog" of Tansley's (1939) British bogs.

Tussock tundra is a vegetation type which predominates in the lowlying tundra regions of Alaska: Seward Peninsula (Porsild, 1941; Sigafoos, 1951) and north of the Brooks Range (according to botanists Lloyd Spetzman, Quentin Jones and A. R. Hodgdon). It resembles the "Eriophoretum" of Tansley's (1939) British bogs.

The Bogs

The older parts of the floodplain, near the valley sides, are nearly entirely covered with vast bogs. The bogs occupy about three-quarters of the mature floodplain area, beyond the zone of active meanders, and exist as a contradiction to classical ideas of plant succession on a floodplain. The classical concept of plant succession on a floodplain holds true in temperate regions and has changed little since Theophrastus first described it in the Aegean region in his *Inquiry into Plants*. The bogs are described in detail here before going on to interpretation of process, formation and development.

GEOLOGICAL DESCRIPTION OF THE BOGS [6]

From a geological point of view, there are two essential parts of the lowland "flats": 1) the peat bogs with their included ponds and lakes and 2) the surface of the lowland which surrounds them or occurs in them as islands. In the Upper Kuskokwim River Regions this "solid land" is forested, chiefly with Black Spruce, but E. Muller, Geologist, tells me that in the Bristol Bay Region of Alaska similar patterns are developed without forests.

1) The peat bogs. The bogs are a water-sodden mass of the dead accumulations of past years plant growth, chiefly sphagnum. A more or less closed vegetational cover of mosses, sedges, and low brush grows on the surface. Bogs may be more or less circular or elongate, from a few yards to many hundreds of yards long. If bog-vegetation has colonized a drainage system or taken over a low slope, the bog may extend for several miles. In general the bogs are found on level or gently sloping surfaces underlain by silt, fine sand and organic matter, or other materials or conditions which impede subsurface drainage.

The carpet of mat plants mosses and lichens corresponds to *Hochtundra* or *Flechtentundra* of Middendorf (1864). This is equivalent to dry tundra of Sigafoos (1951), arctic-alpine zone of Tansley (1939) and montane vegetation of Pearsall (1950). It is what Europeans call the Arctic vegetation above the alpine meadows.

6) Geological is here used to contrast with the botanical or vegetational description. The geological description is of the topographic features or the physiography. In the development of the forms it is impossible to separate the physiographic process from the biological but in description it is convenient to do so.

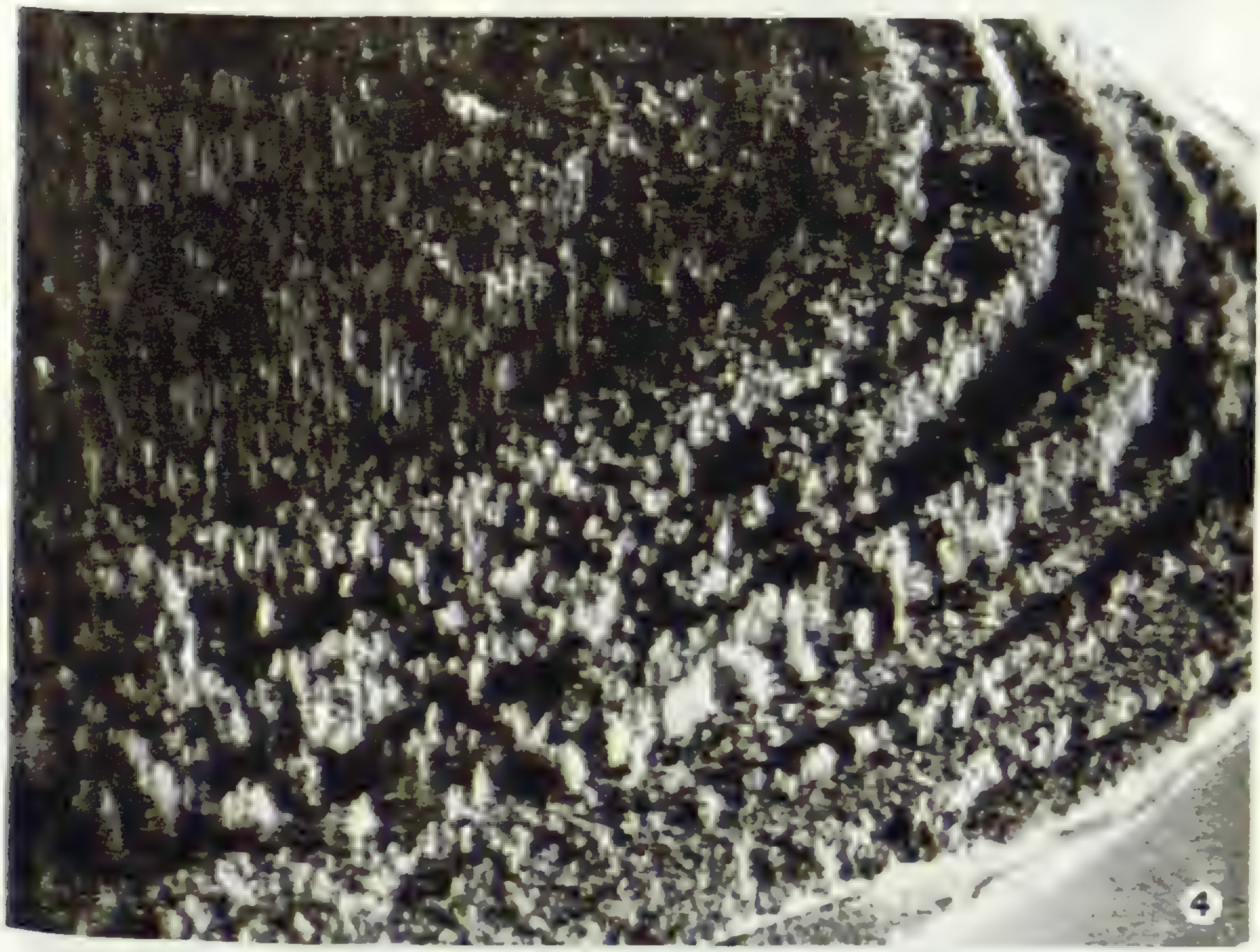

FIGURE 3. MUCK EXPOSED IN A RIVER CUT 70 MILES EAST OF MCGRATH. A layer of muck is exposed all across the picture half way up the bank. The lower limit is sharply marked on the left. On the left, black muck extends to the top of the bank, but on the right it grades upward into a dry, tan silt. The terrace-top is about 100 feet above river level.

FIGURE 4. LOW ALTITUDE PHOTOGRAPH OF THE FLOODPLAIN OF THE KUSKOKWIM. Zonation of the vegetation on the depositing slope of the river is shown. The smooth gray pattern in the bottom-right corner is thickets of Felt-leaved Willow with ridges occupied by Balsam Poplar. These constitute Phase I. The top left corner is Phase II, consists of tall White Spruce

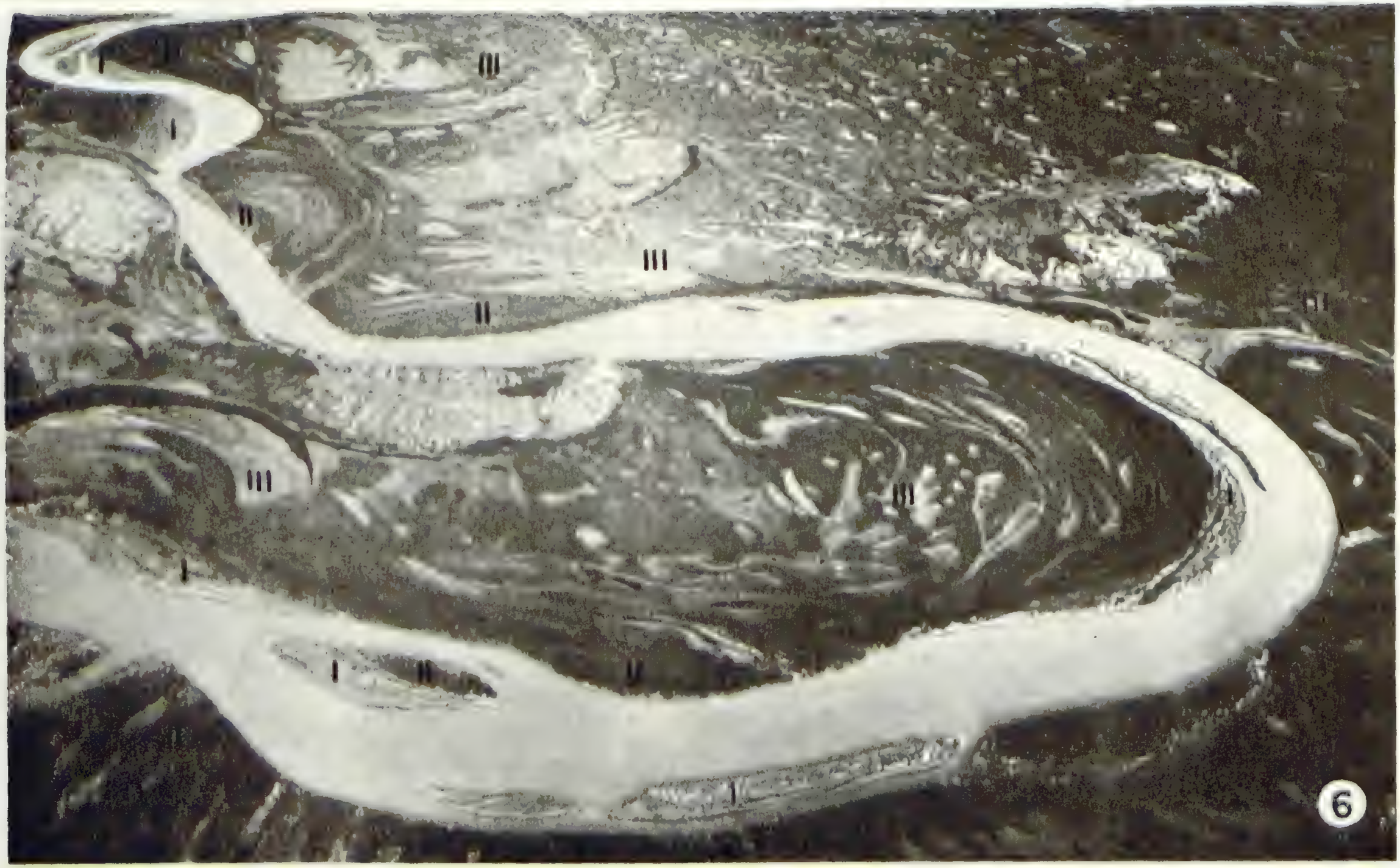

FIGURE 6. AERIAL PHOTOGRAPH FROM 10,000 FEET LOOKING EAST UP THE KUSKOKWIM RIVER FROM NEAR MCGRATH. Phase I is restricted. It is made up of those areas where sloughs are parallel to the river and tall deciduous trees grow. The deciduous trees in fall foliage are the lightest tone. Phase II is of larger extent where sloughs are at an angle to the river and a forest of White Spruce grows, the darkest tone Phase III occupies the largest area, that of the mottled, irregular pattern. Swale and ox-bow patterns persist. The smooth light tone is chiefly sedge meadows The sand dunes on the high terrace covered with patches of muskeg and Aspen groves appear on the right. (Photograph

The depth to mineral soil is variable where known. In cases in which bogs now occupy former channels of the Kuskokwim River the depth can be assumed to be 30 to 40 feet or more. Beds of peat 30 feet high are at present exposed in the river banks, and the exposures in the high terraces, such as that 70 miles up the Kuskokwim River from McGrath, show mucks 35 feet thick[7] (Figure 3). Auger holes 6 feet deep into the bogs have encountered no perennially frozen material and penetrated only peat or peat with a silt content which increases conspicuously with increasing depth.

Deposits which underlie areas of peat bogs exposed by cutting of the river are of the following types: 1) gray, river-deposited, bedded silts alternating with beds of peat; 2) gray, river-deposited silts overlain by deposits of peat of various thicknesses; 3) a mixture of silt and finely divided organic matter, often frozen, which when it thaws has the characteristic fetid odor of muck. Involutions have been found under bogs and forests in the bedded deposits near bed-rock hills, but most of the gray, organic silts show no bedding and no signs of involutions.

2) The non-bog surface in most of the Upper Kuskokwim River Region is readily separated from the bogs because it is covered with a forest of Black Spruce. Below the living mosses which carpet the floor of this forest is a deposit of peat, usually dry, from 1—25 feet, but usually 2—3 feet thick. Below this are the sediments of the alluvial lowlands which vary according to the history of their deposition as described in the preceding paragraph. The top of the perennially frozen ground (permafrost table) generally lies 18—24 inches under the carpet of mosses. Small ice lenses are widespread in the perennially frozen ground.

The characteristics of the contact between the non-bog surfaces of the lowland and the bogs vary according to whether the bog is advancing or is being invaded by peat-forming vegetation.

VEGETATIONAL DESCRIPTION OF THE BOGS

1. The vegetation of the flats areas is also divisible into

7) This muck exposure is sharply separated from the underlying bedded silt for about 40 horizontal feet then grades into a silt bank. There are no traces of bedding in the muck nor of involutions inside it or along the contact with the silt below it indicating soil movement.

quaking bogs and raised areas. The open surfaces of the quaking bogs match in detail the available descriptions of bogs in central Russia (Katz, 1926) and northern Finland (Cajander, 1913; Auer, 1920).

The bog surfaces are covered by a variety of vegetational associations. Each association is a unit and is repeated as a unit in the mosaic of vegetation, but so various are the possible combinations, that at first there seems to be no order either to the vegetation or to the shifting patterns.

The associations are 1) sedge meadow, 2) areas of shallow water with mud bottoms and scattered emergent aquatics, 3) areas of low or 4) tall heaths and dwarf birches with a dense sphagnum carpet, 5) areas where the water flows across the entire surface and mosses are nearly lacking, 6) small open ponds, 7) areas of net-like patterns of bog ridges and bog hollows.

The carpet of vegetation in those bogs which have formed by colonization of a body of deep, open water such as an ox-bow lake is much less compacted than that of shallow bogs.

The silt-bottomed, shelving beaches of ox-bow or bar lakes [8] have a characteristic flora which may persist when the area is invaded by sphagnum. This history of formation of such areas can be read in their vegetational patterns and flora.

2. The non-bog surfaces, which include the elevated islands in the bogs and the main lowland surface, like the isolated patches of forest colonizing on the bog surface, have a heavy moss carpet of *Sphagnum* and woodland mosses (*Hylocomium*, *Pleurozium* and *Dicranum*), often with an extensive growth of lichens (*Cladonia*, *Cetraria*, *Peltigera*, and *Nephroma*) underlain by varying thicknesses of peat.

There is a dense growth of low heath and dwarf birch shrubs (*Betula nana* var. *sibirica*) about 2 feet high, scattered tall willows (*Salix Bebbiana*, *S. pulchra*, *S. Scouleriana*) and alders (*Alnus crispa* and *A. tenuifolia*) 8—15 feet high, a few White Birch trees (especially *Betula papyrifera* var. *kenaica*) and variable numbers of Larch (*Larix laricina* var. *alaskana*) in the forest of Black

8) A bar lake is a body of water enclosed by the deposition of a crescentic bar or depositional scroll on the inside of a meander bend of a river (Melton, 1936).

Spruce. This is by far the most widespread forest of the lowlands and gentle slopes. It covers about 6700 square miles or 75% of the total area of the upper Kuskokwim River Region. Larch is most conspicuous among islands and rows of trees on the surface of the bogs. On the islands formed by slump from the terrace escarpments, there may be dense groves of White Spruce and Birch [9].

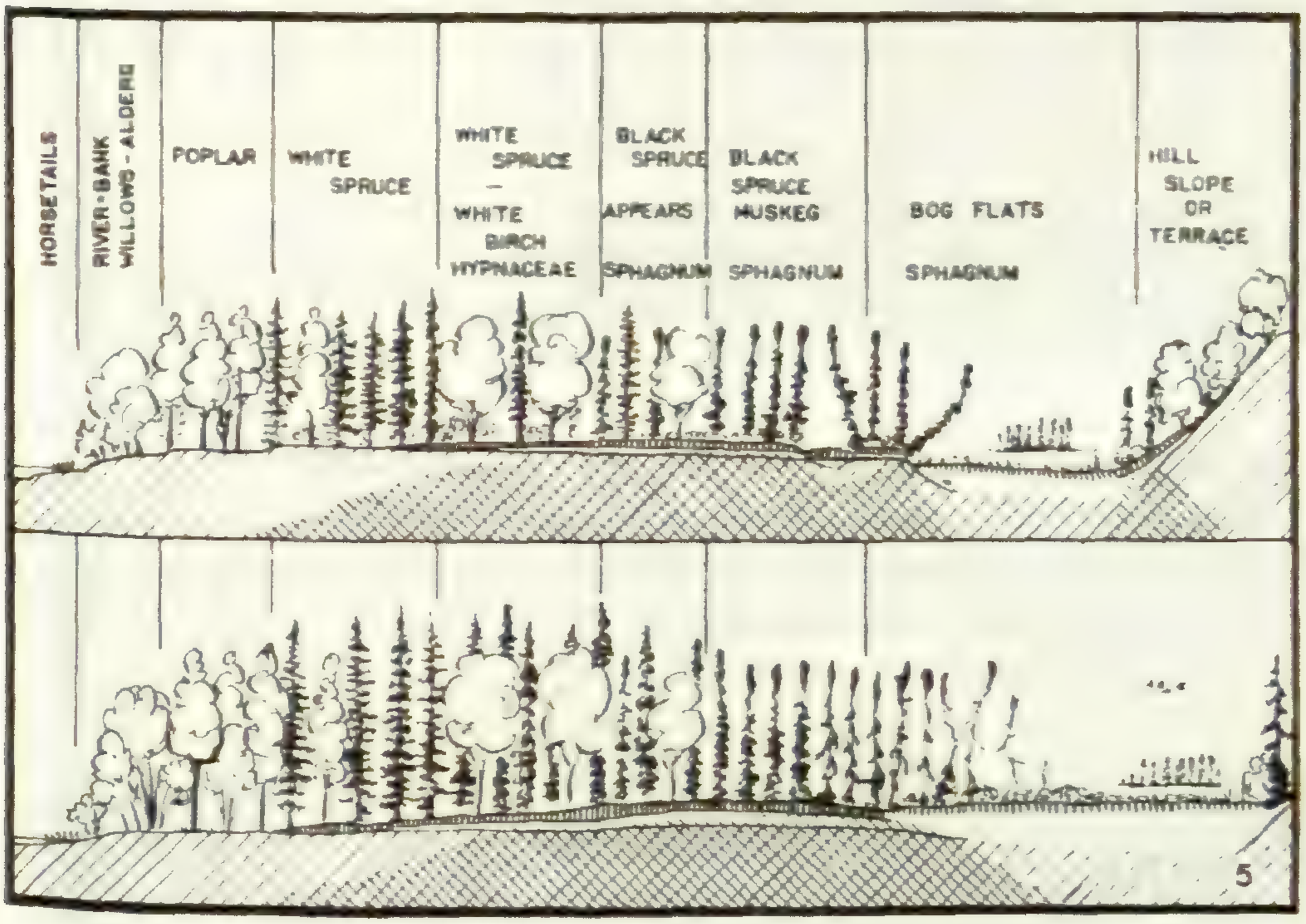

FIGURE 5. IDEALIZED CROSS-SECTION OF THE FLOODPLAIN. The upper diagram represents areas where bogs have formed by thawing. the lower, areas where bogs have formed coincident with a rise of water table and swamping. Vertical hatching is living mosses; white areas are peat accumulations; diagonally hatched areas (top-right to bottom-left) are sediments; diagonally hatched areas (top-left to bottom-right) are permafrost.

9) Where the river has cut against the high terrace leaving a bank 60-100 feet high, then migrated away again, isolated parts of the terrace escarpment have fallen into the former river channels and appear in the bogs which have formed there as low mounds with sloping bedding.

PHYSIOGRAPHIC PROCESSES

The Floodplain Surface

The permafrost table gradually rises from the younger to the older parts of the slip-off slope of the floodplain (Figures 5 and 12) because on the older surfaces the mosses are better established and thicker and act as better insulation. Although when frozen the moss mat allows loss of heat by radiation during the winter, when thawed and especially when dry the moss mat and peat preserve frost in the ground during the summer thaw (Muller 1947 p. 53). The oldest and highest floodplain surfaces, with the thickest moss carpet, have the highest permafrost table, both in the Upper Kuskokwim River Region and in the Galena Region, 120 miles to the north on the floodplain of the Yukon River (Péwé 1948). Peat under the forests was largely dried out by the end of July in the Upper Kuskokwim Region.

The Divisions of the Floodplain

Péwé in his discussion of the terrain of the Galena area divided the floodplain into four phases. These are clearly marked on the floodplains in the Upper Kuskokwim Region. The criteria he used for distinguishing the phases are drainage pattern, distribution of vegetation, depth to permafrost, elevation, lithology of sediments, character of the river bank, and distribution of drift wood. He has divided the younger surfaces into two phases:

I. *Linear Phase* youngest — Distinct linear lakes parallel to the river, no integration of drainage, large deciduous trees, permafrost absent or low, no large masses of ground-ice.

II. *Advanced Linear Phase* — Distinct linear lakes, some integration of drainage, large coniferous trees, slightly higher permafrost table, no large masses of ground-ice.

The youngest surfaces of the floodplain (Figures 4 and 6) are the slip-off slopes on the inside of a bend of the meandering river. In its migration, the river is depositing sand and silt, building and extending these surfaces. The surface is irregular, scarred with the pattern of bars and swales. Floodwaters flow through the larger swales filling them rapidly with alluvium. The first stage of succession on the younger surface is tall willows and alders,

followed by a deciduous forest, Phase I, and then by a tall mixed deciduous and coniferous forest, Phase II. The outlines of the recently abandoned channels and bar-lakes are not modified in Phases I and II except by the colonization of the shallow water by vegetation.

The migrating meanders of the river tend to remain within a certain zone, which is the zone of active meanders, rather than wandering over the whole valley bottom. For this reason the surface of the floodplain beyond the zone of active meanders is significantly older. It has not been disturbed by the cutting of the river for a long time. The younger surfaces show the patterns and the forests of recently deposited surfaces clearly, while the older parts show the floodplain patterns partially obliterated. The rise of the permafrost table has eliminated the mesophytic tree species over large areas, and bogs and scattered stunted trees in a "forest-tundra" have replaced them. Transitions do exist and are best shown on the floodplains of the larger rivers such as those of the main Kuskokwim and of the Yukon at Galena, but in general there is a marked break in the conditions of soil and vegetation at the edge of the zone of active meanders.

In Péwé's classification, the older surfaces are also divided into two phases:

III. *Coalescent Phase* — coalescing linear lakes generally at an angle to the river, coniferous trees, some "tundra", high permafrost table, and no large masses of ground-ice.

IV. *Scalloped Phase* (the oldest) — irregular shaped lakes with scalloped borders, integrated drainage, stunted coniferous trees, much "tundra", very high permafrost table, much ground-ice.

Péwé's Phase III is evident on the floodplain of the Kuskokwim behind the tall forest of White Spruce and Birch (Figures 6 and 7). It is the area of transition at the edge of the zone of active meanders.

The oldest surfaces of the floodplain are found on the lake-dotted surface near the Big River and Medfra, or again in the Nixon Fork Valley. This physiographically corresponds to Péwé's Phase IV. On the relatively level surfaces of the main alluvium on the Medfra Lake Terrace lakes are scattered at random and the bogs developed within them (Figure 7). In the Nixon Fork Valley re-entrant, however, the alluvium is gently sloping and there is a down-slope component in the forces influencing the

FIGURE 7. AERIAL PHOTOGRAPH FROM 10,000 FEET LOOKING EAST UP THE SOUTH FORK FROM EAR MEDFRA. Phases I and II are limited in extent, but Phases III and IV are conspicuous. hase IV is the Medfra Lake Terrace, on the right in the middle distance, where smooth-shored kes are now occupied by bogs. The darkest tone on the left near the river is White Spruce. he mottled tone in the foreground is Black Spruce with some White Spruce. The light tone n the rolling surface around the bogs is open Black Spruce muskeg. The photograph was ken in winter and snow cover makes the bogs appear white. (Photograph courtesy of the .S. Army Air Forces).

FIGURE 8. AERIAL PHOTOGRAPH FROM 10,000 FEET LOOKING EAST OVER THE NIXON FOR FLATS. Bogs have expanded by thawing of perennially frozen ground. The whole area i Phase IV. Movement of water through the bogs is responsible for their long down-slop component and makes them soligenous bogs of the Scandinavian classifications. The darke tones are standing water with emergent aquatics: the intermediate tone is Black Spruce fores and the lightest tone is sedge meadows and bog brush. (Photograph courtesy of the U.S. Arm Air Forces).

formation of bogs. This has led to down-slope orientation of the long axes of the bogs and of the included islands (Figures 2 and 8). Characteristic microtopographic and vegetational features on the bog surfaces have resulted from these same slope components. Because Phase IV does not occur where the Kuskokwim River is actively cutting against the floodplain, the distribution of frozen banks along that river is not as conspicuous as it is along the Yukon in the Galena area. Another difference exists between the Kuskokwim Region and the Galena Region. The ponds and lakes which are open water in the Galena Region, as they are in the Nabesna-Chisana Region described by Wallace (1948), are regional bogs in the Upper Kuskokwim Region.

Péwé (1948, p. 24) expresses some doubt that the Phase IV of the floodplain at Galena is simply an older stage and suggests a slightly more complicated geological history. The distribution of this type of surface in the Upper Kuskokwim River Region (Nixon Fork Lowland and Medfra Lake Terrace) agrees.

The Bogs

It was pointed out that the rise in permafrost table in the floodplain deposits is correlated with the thickness of the moss mat. Also dependent on the growth of mosses (first *Hypnaceae* and then *Sphagnaceae*) are the establishment and expansion of the Black Spruce forests and peat bogs. The mosses responsible are highly adapted to soak up and hold water, so that once established they maintain their own water-soaked environment unless exposed to excessive evaporation or fire or are otherwise disturbed. Muller (1947, p. 53) says that peat (without saying what kind) can absorb water up to 300% of its volume. The moisture contained in the bases and dead remnants of sphagnum mosses has a low pH and nearly anaerobic conditions. This has an antibiotic effect on bacteria of decay so that the remains of plants collect and are preserved as peat. Tansley (1939, p. 676) has summarized the important effects of sphagnum peat according to recent knowledge, based largely on the work of Skene (1915), Watson (1918) and Pearsall (1938).

Frost in the ground decreases sub-surface percolation and thawing of the annual frost is a source of water. The adaptation for holding moisture by peat mosses decreases surface run-off.

The fine-grained materials of the alluvial lowlands also decrease percolation. The low slopes of the lowlands allow the collection of bodies of water, and the short cool summers do not return large amounts of moisture to the air by evaporation and transpiration. Each of these conditions exaggerates the effects of the others, although they are probably not all operating at any one place or time. The combination of their effects is responsible, however, for the saturation of the alluvial lowlands.

Soil movement and alluviation from minor streams has nearly obliterated the break in slope from bedrock hills to depositional slopes and from depositional slopes to the floodplain. Bogs colonize moving water of the minor streams responsible for alluviation at the margin of the floodplain and can occupy slopes as steep 3°. For these reasons there is no sharp separation between the surface of the floodplain and the depositional slopes and it is not possible to say that bogs are restricted to the floodplain and terraces. They appear wherever the collection of water will allow it.

FORMATION OF BOGS

In the Upper Kuskokwim Region peat bogs form in three general ways: 1) by the colonization of a body of water by peat forming plants, 2) by the invasion of the lowlands by swamp-making vegetation (forest mosses, then sphagnum), and 3) locally by the thawing of perennially frozen ground, depergelation (regional and climatic thawing of perennially frozen ground, Bryan, 1946).

The first involves the colonization of a body of open water by immersed aquatic mosses (*Sphagnum*, *Calliergon* and *Drepanocladus*), upon whose remains and dependent upon whose growth the vegetative shoots of sedges can find support. Succeeding years' growth of these plants weaves a tighter and tighter carpet, while their dead parts sink to the bottom and are preserved under the cold anaerobic conditions. Gradually, as plant remains fill the water, less and less hydrophytic vegetation is able to become established and a quaking bog is formed. This process is common in the northern United States, and bogs formed in this way correspond to topogenous mires or basin bogs of the von Post (1937) classification.

The second type of origin was described in considerable detail by Cajander (1913). He calls it, the "Versumpfung des Waldbodens" [10]. This process was described in the United States by Shaler (1890) and was well known and earlier described from Europe. In it mosses colonize low areas or depressions and hold moisture collecting there from rainfall, surface run-off or soil-water percolation. The mosses (and the conditions that allowed their establishment) continue and spread, gradually occupying more and more of the forest floor until the sodden conditions kill off the forest and a shallow bog is formed. A gradual rise in the ground-water level on the alluvial lowlands of the Upper Kuskokwim is occurring because of inadequate run-off of drainage from the hill slopes and terraces and the other factors mentioned previously. Sphagnum has colonized the wet places and huge areas have become shallow bogs (Figures 6 and 7, Phase III).

The third method of formation and spread of bogs depends on the presence of perennially frozen ground and the destruction of it by thawing at the banks of a quaking bog. The process is closely related to that described by Wallace (1948), Hopkins (1949) and Black and Barksdale (1949). Taber (1929) and Muller (1947, p. 65) have shown that silts and other fine-grained soil materials tend to absorb moisture on freezing so that they commonly contain a considerably greater amount of water when frozen than when thawed. This moisture segregates as crystals and lenses of ice of various sizes. The thawing of perennially frozen silt will produce a depression of considerable depth (Muller, 1947, p. 84), 15 feet in some examples in the Upper Kuskokwim. Because the moss carpet acts as an insulation to the frozen ground, thawing can be started by any break in it. In such a depression water will collect, be warmed by the sun and continue to thaw the ground around it. A depression or break in the moss carpet can be caused by a fire, a tree blow-down, the bursting of a frost-built hummock or *pingo*, a well-used game trail, a bear's meat cache, the bank of a small brook, or the water that collects in sphagnum mosses invading the forest by the swamping process. Thawing of frozen

10) This is the process for which von Post (1937) has coined the word "paludification", intending to anglicise the German term *Versumpfung* or Swedish *Försumpning*. The word has the twin disadvantages of being of combined classical and English origin and meaning no more than the common English word "swamping" can. The word was used by Wenner (1947) referring to the bogs of Labrador, however, as if it were in general usage.

FIGURE 9. LOW ALTITUDE AERIAL PHOTOGRAPH OF THE NIXON FORK FLATS. These bogs are panding by thawing into the frozen floodplain sediments. On the left side of the picture, al base-level is the river; in the foreground, base-level is above the channel. The rolling rface between bogs has on it scattered Black Spruce and Larch.

FIGURE 10. SURFACE VIEW OF BOG VEGETATION. A meadow of coarse sedges is shown o the edge of a bog actively undermining the Black Spruce forest in the background. (Photograp taken by J. R. Williams at Chena Slough near Fairbanks).

FIGURE 11 SURFACE VIEW OF BOG VEGETATION. The bog brush shown is typical of larg areas of stabilized bog surfaces. Black Spruce has grown on the raised area in the middl while angular growth of trees in the forest in the background shows the effects of soi instability.

silts destroys their coherence, so that they slump and increase the depression. Once the thawing has started, it expands in all directions and the pattern that is produced depends on the direction and strength of the forces that affect the rate of retreat of the banks (Figures 2, 8, 9, 10, and 22). Thawing expands from neighboring centers of origin to coalesce, and the result is a large area of anastomosing bogs with isolated islands or peninsulas of the former floodplain surface. The banks of these bogs are abrupt (Figures 9, 10 and 22), and the moss and heath mat of the forest floor hangs over into the bog or is broken, exposing frozen or thawing silt. At the edge of the banks a depression is formed which fills with water. It is called a moat here to separate it from similar features of other types of bogs [11]. The moat channels run-off and melt-water from the thawing surface and encourages further thawing of the frozen bank.

Aquatic sphagna and sedges colonize the water-filled depression as they do in bog succession in a pond. Less hydrophytic sphagna and sedges follow which allow the growth of heath and birch shrubs as the mat tightens. In this way the bog vegetation occupies the expanding depression.

On the swamp-lowland of Nixon Fork Valley (Figures 2 and 8) the bogs are oriented parallel to drainage channels, and the islands have their long axes parallel to the line of slope. This indicates that there is a significant down-slope component to the movement of water in the bogs. It shows evidence of the relationship of these bogs to the soligenous types of Scandinavia in origin or physiography, as well as in the vegetation and floristics that will be described in detail later.

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11) A moat is a deep-water canal, often 4-6 feet deep, at the edge of a bog that is actively expanding by thawing of the surrounding frozen alluvium. A moat is wider than the marginal channel of most American bogs (called Yazoo stream in parts of the Pacific States) which is formed by the break in vegetation resulting from the rise of the floating bog-mat when flooded in the spring. A *lagg* of *Hochmoor* or ombrogenous mires is formed as a result of drainage of water from a convex bog.

A moat may consist of an area of open water several yards across, with pond lilies and other aquatics in it, but in most bogs it is a broad zone of coarse sedges growing in deep water and closely resembles a *lagg*. Skeletons of trees that have been slumped into the bogs as shown in Figure 10, are common in the moats. Moats are not universal in the Upper Kuskokwim River Region, but active expansion of bogs is similarly not universal.

DISTRIBUTION OF BOG TYPES

The three processes of bog formation of course do not segregate neatly into regional types, but on each of the three surfaces which show a maximum development of bogs, one of the processes is most conspicuous. First, on the floodplain of the Kuskokwim and many of the larger tributaries of the main valley, especially Péwé's Phase III, the bogs form largely by colonization of ox-bow and bar-lakes and by invasion of the floodplain forest by a swamping correlated with rise of the water table (Figure 6). Second, on the older part of the floodplain surface, Péwé's Phase IV, near Medfra (Figure 7), the bogs have formed by colonization of the shallow water of lakes randomly scattered over the surface. Large bog areas on this surface also result from expansion of bog vegetation along minor drainage channels between lakes. Third, on the lowland in the reëntrant occupied by the Nixon Fork of the Takotna, also Péwé's Phase IV, are those bogs formed by thawing of perennially frozen ground along drainage channels (Figures 2, 8, 9 and 22).

Bogs of the type found widely on the younger parts of the floodplain of the Kuskokwim (Figure 6) are large and irregular in outline, often reflecting the patterns of deposition of the alluvium (the ox-bow and bar-lakes, bar and swale topography). The forested parts are usually close to the same level as the bog surface, and the contact is on a gentle slope. Tongues of bog extend into the forest and large portions of the interior of the forest have a thick, soft moss mat where the swamping process is starting to have an effect. In some areas the non-bog surface is higher, has scalloped outlines, and is separated from the bog by an escarpment. Islands formed by slump from terrace escarpments are found in this type of bog. The forested surface has a dense mixed forest of Black and White Spruce or tall Black Spruce.

The bogs on the oldest part of the floodplain near Medfra have colonized scattered irregularly shaped basins (Figure 7). In them, striking flat-iron-shaped lakes persist. The lakes were originally formed as a result of processes that are not understood but which involve depergelation. The outline of the lake basin is often scalloped and the basin oriented as if under the control of forces similar to those suggested by Black and Barksdale (1949) and Hopkins (1949), migration of lakes by thawing of perennially

frozen ground in their leeward banks as a result of the effects of warm winds and waves. This is clearly not the entire explanation, however. Bog vegetation has colonized these lakes and the edge of the carpet subsequently has been shaped into long crescents by the wind and ice.

The explanation of these smoothed, triangular shore-lines involves the fact that in the spring when thawing, which takes place first along the shore, has freed an island of ice in the center, this ice is blown around by the wind. It bumps repeatedly against the lee shore and crushes and flattens the pliable vegetation carpet. The waves stirred up by summer winds beat against the same lee shores and erode them. Both forces act only at the edges of the carpet of vegetation and for that reason buckle the edges into the peat ridges which are conspicuous elements of the margins of bog-margined lakes. The triangular lake basin at present is independent of the original outline.

In addition to the bogs which surround the lakes, bogs on this Medfra Lake Terrace have expanded up drainage channels and occupied nearly all low places by swamping. The surface has a subdued rolling topography covered with a thin, stunted Black Spruce forest. Intricately interconnecting bogs extend in and out of the low, rolling surface.

The bogs found in the reëntrant valley of the Nixon Fork (Figures 2, 8 and 9) are formed almost entirely by expansion from drainage channels by thawing in the bog banks (Figure 10). They occur on slopes of 1°—4° and accordingly vary in the degree to which down-slope movement of water affects their shape. Those on nearly level surfaces have scalloped margins and shapes similar to the lakes illustrated by Péwé (1948) and Wallace (1948) (Figures 9 and 22). Characteristically, the bogs are elongated down slope, have abrupt margins, no describable shape and are characterized over most of their area by the patterns of bog vegetation called *Strangmoor* in German (Cajander, 1913). In parts of the Nixon Fork Lowland they have obliterated the forest from areas measurable in tens of square miles (Figure 2). The forests in these lowlands are of tall Black Spruce and Larch.

TRANSFORMATION OF THE BOG BASIN

As soon as a wet depression or body of water is colonized by bog vegetation, slow processes start to fill it with plant remains.

They may eventually transform it to a peat-filled forested hollow. Changes in water level or in frost activity in the bog can, however, reverse the direction of this change and return the area to open bog or shallow water. This is not a unidirectional development toward a climax vegetation as recent discussions of peat bogs in Alaska seem to indicate.

With the establishment of vegetation, collection of plant remains starts. Dead mosses, sedge roots and rootstocks, culms and stolons are preserved in the cold, anaerobic conditions that inhibit the growth of bacteria of decay. But percolation of soil water through the matrix of this organic mass allows partial decomposition of much of the organic material and penetration of silt. Silt-bearing winds, annual spring or summer floods, water moving through the bogs, and the mineral soil contributed to the bog by the slumping of the banks add mineral material to the growing mass. During the spring thaw the whole lowland is a sea of moving water, sometimes clear, sometimes cloudy with silt. As the peat and silt deposits build up and are consolidated by their own weight, they form a firmer substrate which allows colonization by progressively less hydrophytic vegetation. The firmer substrate provided as the peat builds up allows the establishment, eventually, of woodland sphagna, and brush (heaths and dwarf birches). Finally, a Black Spruce, Larch, or mixed forest can appear on the surface, growing on a consolidated deposit of peat and silt. This organic soil (Radforth, 1952) is protected from loss of heat by the moss carpet, and, as it is increasingly compacted, is less and less subject to the continued flow of bog waters which tend to unify its temperature. Finally, water no longer percolates freely and under these conditions the ground may freeze and remain frozen, forming perennially frozen ground. Freezing leads to the establishment of discrete ice lenses in the deposit, increasing the volume of peat and silt (Muller, 1947), and the result of all these processes is to raise the level of the forest floor. The drier and more stable conditions in the floor which result are usually marked by expansion of the forest and extensive growth of lichens. The forest and its underlying deposits are similar to those originally destroyed by bog advances.

The advance of bogs into the frozen alluvium by thawing is in action at the same time that the collection of organic remains is filling sodden depressions. The two antagonistic processes form

a cycle which is in action on the alluvial lowlands at present and has had wide-reaching effects on the sediments of the lowlands in the past.

Geobotanical Processes and Sedimentary Deposits

Field observations which must be accounted for include: 1) the present patterns of bogs, of forests being undermined, and of patches of developing forest; 2) the deposits exposed in river-cuts under present areas of bogs. The vegetation patterns are to be explained as dependent on microtopographic features produced by thawing of frozen silt at the advancing margin of the bog, and by other geological processes in the substrate, rather than simply "vegetational development". They will be discussed in the chapter on Vegetation.

EXPLANATION OF FIELD OBSERVATIONS

The deposits found under present bogs can be explained in terms of processes visible on the floodplain surfaces. Strata of peat are explained by the presence of peat-forming vegetation on the floodplain during aggradation. The interbedding with river-borne silts points to periods of shifting channels of the river and to floods. Peat layers near the surface underlie living peat-forming vegetation.

An explanation of the formation of mucks remains. Tuck (1940), Eardley (1937) and Taber (1943) have discussed the formation of muck and Péwé has in preparation an interpretation of muck deposits in the Fairbanks district. All of these interpretations indicate that muck formation occurs on valley sides. In general they suggest that clouds of wind-borne silts have been carried from the bare river beds of braided streams and deposited on the hills; these silts are moved by solifluction and alluviation down to the valley sides, incorporating organic material into the deposits as they gather. Péwé (1950, 1951) has shown that much of the silts of the uplands in the Fairbanks region is wind blown (loess). He has explained muck formation there to me as transport by small streams of loessal deposits from the hills into the valley sides where they are incorporated as minor delta deposits with finely divided organic material, and then frozen. These ex-

planations do not satisfactorily account for muck deposits in valley centers. In the 80-foot terrace, 75 miles upstream from McGrath, there is a deposit of muck about 35 feet thick (Figure 3), but the Kuskokwim River lies between this muck deposit and the nearest bedrock hills. It may be that the Kuskokwim River once drained South between the Alaska Range and the Lime Hills, but until this is proven to be the case, solifluction or minor stream deposition cannot have deposited these sediments across the river, and the nearest other source of the solifluction materials is the Alaska Range, 40 miles away. I believe that the geological and botanical processes in the regional bogs are adequate for the formation of such deposits.

The materials called muck are nearly always frozen. For their formation it is assumed that perennially frozen ground plays an important part and it does in the bog-forest cycles in the Upper Kuskokwim Region. Climatic conditions have to be such that finely divided organic material is preserved in a semi-decomposed state (peat) while being thoroughly mixed with fine-grained mineral material. Maddren has pointed out what is conspicuous, that peat is the most widespread and characteristic of recent deposits (1910) [12].

Two processes are available for the formation of mucks: 1) repeated cycles in the advancing of bogs by thawing, (which incorporate slumped materials into the bogs) or swamping (*Versumpfung*); 2) collection of aeolian and alluvial silt on the surfaces of sedge-meadow bogs. The soligenous nature of these bogs will lead to the incorporation of the mineral material into the peaty material below. Both of these processes must take place during a period of stream aggradation.

Cycles

The first process involves repeated cycles of bog invasion by thawing in the frozen lowland silts. Each invasion into the forest surface causes slumping of the vegetation carpet, and incorporation of the materials that had been at or near the surface into the deposits at various levels in the bog deposits, determined by

12) The quaking bogs involved in the cycles are often deep and can act as traps to entomb large mammals. The inclusion of dismembered, often unbroken, fossilized large-mammal remains is a characteristic of mucks in some areas.

chance. The result is a thorough stirring of the various strata, obliterating their original sequential stratigraphic positions. Successive cycles will disrupt stratigraphy throughout the sediments and produce a more or less homogeneous mixture of sediments with organic material.

A secondary possibility is one of a long series of cycles of forest and bog with the destruction of the forest by swamping (*Versumpfung*). Bog processes restore the forest, and a subsequent or continued rise in ground water could drown the forest again. This would produce a varying pattern according to the various levels in the area, and according to the rate of plant growth. Some areas could keep ahead and be in forest while others would lag behind and be incorporated into the bogs. A cycle similar to the freeze-thaw cycle would result, and it would not be directly dependent on the behavior of perennially frozen ground. But in this case the deposits would be alternating strata of peaty and silty materials or stratified organic silts.

Soligenous Mires

The second important source of muck formation depends on the soligenous nature of the bogs. Bogs on surfaces of low slope develop from colonizing of drainage channels (Figures 2 and 8). The Swedish students recognize that the flow of water through the bogs (Sjörs, 1948, p. 289) creates a special bog type (soligenous as opposed to ombrogenous or topogenous) and point out that the water courses are usually marked by fens (sedge meadows or areas of *Carex rostrata*, *Eriophorum angustifolium* or *E. Chamissonis*). Flow of water through bogs is obstructed by the vegetation, and any load the water may carry is soon deposited. The flow of water through the bogs can be considered as an agent of transport of materials from the hill slopes, carrying the fine-grained materials of residual soils or loess. Spring melt-water floods spread considerable quantities of river-borne materials over the lowlands, and wind-blown silts contribute directly to deposits in the bog. In fact, loess deposition on the surface of an active bog in itself is adequate to create muck by incorporation of the silt into organic remains. These inorganic deposits mix with the plant remains, settle or are carried by water into the bogs, and are compacted with the peat. Repeated tests by borings to depths

up to 6 feet in bogs that are part of the flats system indicate a conspicuous rise in mineral content with increasing depth. This is not the case in typical raised bogs (ombrogenous) where borings indicate only peat at depth.

Cycles of disturbance of the strata laid down in the bogs, and repeated exposure to circulation of water carrying some oxygen and greater or lesser amounts of silt, will break up and distribute the organic material and mix it with inorganic, producing an unstratified deposit of finely divided organic materials and silt. Circulation of water will also allow partial decomposition of the organic material. The rivers and streams may sweep back and forth over the valley, seeming to erode. In the same way the thawing activity of the bogs may seem to be grading the lower slopes to the stream banks, but if the overall pattern is one of stream deposition the sediments in the valley will be thickening. The development of deep deposits of such muck can be visualized in terms of repeated cycles of bog and forest, freeze and thaw, or of silt collection in a soligenous bog during a cycle of stream aggradation.

These processes explain the formation of muck deposits in valley centers such as those along the Kuskokwim and along the Yukon at Galena (Péwé, 1948).

BASE LEVEL AND GRADED SLOPES IN THE BOGS

Bogs form in flooded hollows and along water-courses and advance by swamping or slumping due to thawing. The minor drainages which control the water level in such places also control the bogs and it is to be expected that the bogs are adjusted to the base levels of those streams. In general, the processes of erosion accompanying bog development lead to the formation of graded slopes and eventually the bog surfaces will be graded to the master streams.

Actually, over most of the Nixon Fork Lowland for example, as aerial photographs show (Figures 2, 8 and 9), streams meander across the lowland in channels incised into the alluvial surface, and the bogs are in adjustment to temporary base levels on the stream banks rather than to the main streams. In some parts of the valley, such as near Washington Creek (Figure 1), the bogs are connected to such through-stream channels by a number of

brooks. In this case the temporary base level is high enough to allow development of a new series of minor streams and the bog surface must become readjusted to the new base level. Figure 9 shows a series of bogs which are graded to at least two levels, one group to the river bank and the other to the river level. By thawing into the surrounding deposits the bog surface graded to the new, lower base level will migrate upslope producing a knick point and establishing a new graded slope.

Although graded slopes exist in the general terms just described, in detail they are interrupted by micro-relief developed by plant growth. First, the bog phenomena are of short duration when compared to the cycles of aggradation and degradation in the main stream. Redevelopment of frozen ground and forest cover prepares the way for another cycle of invasion by bogs while the base level at the river bank is unchanged, and the advance of the bogs into the frozen surface breaks the continuity of graded slopes. Second, as will be discussed later, bog ridges act as dams and produce step-like low terraces in the graded swamp surface. The bog hollows between ridges are flat, and the next bog hollow is on a lower level as if on a low step. Third, when the ground freezes its volume increases. In an area where parts of the surface are underlain by permafrost and others by thawed materials, there will be irregularity of the surface according to the conditions of frost in the ground. The forested ground, underlain by permafrost, is graded to a previous base level, while several new base levels control the slopes of the bogs.

If the bog advance is completed, the bogs will undermine and destroy the forested surface. But before the forests are eliminated and the whole alluvial lowland graded to the bogs' temporary base level, the bog-filling processes re-establish a peaty substrate which freezes and is no longer a part of the graded surface of the bog. In these ways the botanical processes have interfered with the details of establishment of graded slopes. Furthermore, even geologically, it is rare for a cycle of stream erosion to run its course fully and to produce slopes graded to a base level so that it fits the definition of the proximal portion of a peneplain. Nevertheless, the slopes of the lowland of the Nixon Fork reëntrant are the closest to graded slopes of any in the Upper Kuskokwim River Region.

VEGETATION

The Vegetation of the Lowlands

The changes in the floodplain surface that have been described geologically are directly reflected in the vegetation. The vegetation is closely dependent upon the drainage, the sediment size and the condition of frost in the ground and because of this accurately indicates the changes in these by zonations on the floodplain surface. It is most convenient to describe the vegetation in the categories Péwé established for the floodplain at Galena. Figure 5 is a diagramatic representation of the vegetation zonations on the floodplain of the Upper Kuskokwim River, and Figure 12 a summary of the vegetational changes.

Phase I (*Linear Phase*) of Péwé's classification of the floodplain (Figures 4 and 6) is divisible into three vegetational sections.

1) The recently exposed mud and sand bars are colonized by Horse-tails (*Equisetum arvense*) and Felt-leaved Willows (*Salix alaxensis* var. *longistylis*).

2) The first mud banks and levels just above midsummer high water (about 4 feet above the average river level in the summer) are populated by dense stands of Felt-leaved Willow which may be 30 feet tall. Slightly higher surfaces are populated by other species of willow (*Salix arbusculoides, S. Bebbiana*) and alders (*Alnus tenuifolia*) in addition to the Felt-leaved Willow, which is still the most conspicuous. Beneath these, Horse-tails (*Equisetum arvense*) and some grass (*Calamagrostis canadensis*) cover the ground.

3) The first floodplain surface on top of the banks, is forested with Balsam Poplar (*Populus balsamifera*). The floor is open and on it scattered stands of the following occur: grass (*Calamagrostis canadensis*), Horse-tails (*Equisetum arvense, E. pratense*), herbs such as Pyrola (*Pyrola secunda, P. grandiflora, Moneses uniflora*), Bunchberry (*Cornus canadensis*), Fireweed (*Epilobium angustifolium*), Twinflower (*Linnaea borealis* var. *americana*), Arenaria (*Arenaria lateriflora*), Mountain Cranberry (*Vaccinium Vitis-Idaea* var. *minus*), low shrubs such as rose (*Rosa acicularis*), Currant (*Ribes triste*), High-bush Cranberry (*Viburnum edule*), Osier (*Cornus stolonifera*) and varying numbers of willows and

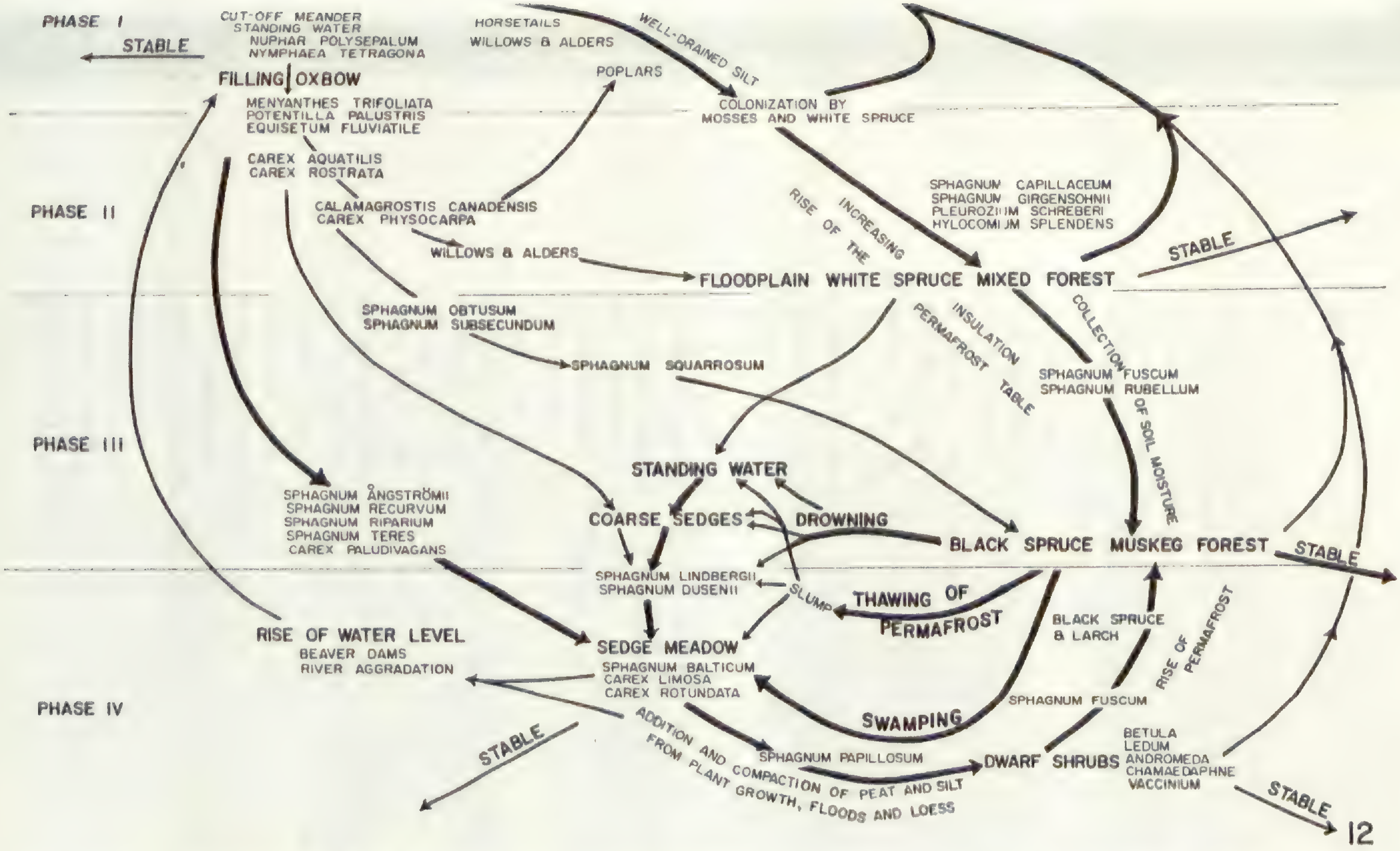

FIGURE 12. FLOW DIAGRAM OF VEGETATION AND PHYSIOGRAPHIC PROCESSES ON THE FLOODPLAIN. This diagram emphasizes the coordination of changes of vegetation and of underlying alluvial sediments. The size of letters is an indication of the relative conspicuousness or area occupied by the various vegetation types, and the breadth of arrows indicates how widespread the changes are. As indicated, several of the vegetation types maintain stability until their site conditions are altered by physiographic processes. This emphasizes the point that the changes indicated are not unidirectional with the age of the floodplain.

alders occurring singly or in thickets. Balsam Poplar is the conspicuous deciduous tree Péwé refers to in his Phase I.

Phase II (*Advanced Linear*) of Péwé's classification corresponds to the single vegetation zone, White Spruce-mixed forest (Figures 4 and 6). On the younger edges of this zone the Balsam Poplar of Phase I is replaced by White Spruce [13], and, as would be expected, widespread forests of White Spruce mixed with Poplar occur.

Under the spruce forests the first patches of mosses appear (*Hylocomium splendens*, *Pleurozium Schreberi*, *Polytrichum commune*, and *Dicranum scoparium*). The patches of mosses become larger and more continuous until they form a complete carpet. The first appearance of a consistent brush layer of heaths, especially Blueberry (*Vaccinium uliginosum* var. *alpinum*) in addition to the shrubs of rose and currant, occurs when the moss carpet is complete. The moss carpet is usually overgrown with Mountain Cranberry. White Birch (*Betula papyrifera* var. *kenaica*) also appears in this older part of the floodplain forest, and at the full development of the forest, when the moss *Ptilium Crista-castrensis* appears, there may be as much as 50% of Birch. Those herbs mentioned as found in the Poplar forest are present, but less common, and a few others appear: Anemone (*Anemone Richardsonii*), Hedysarum (*Hedysarum alpinum*), Star-flower (*Trientalis europaea*), Dewberry (*Rubus arcticus*), and Valerian (*Valeriana capitata*).

This is the vegetation which has been called the Climax Forest or its equivalent (Stoeckeler, 1949; Hultén, 1941). It is the forest of the well-drained mesophytic habitats with a deep permafrost table and is the most productive forest of the region, but, as will be pointed out, it is succeeded by Black Spruce forest and bogs in the course of natural vegetational transformations in the present climate. The transformations which take place are botanical and thus the forest has not achieved a final stage in which it reproduces itself, but instead is still in the process of "development". The succession progresses toward a less mesophytic type and, in life-form terms, is clearly a regression. On

13) The White Spruce in this floodplain forest usually has rather wide-spreading branches, not typically the columnar variety *albertiana*, which is found on the hillsides. Segregation of types or varieties within White Spruce has been discussed by Raup (1946).

such a basis this forest can hardly be considered Climax.

Phase III (*Coalescent Phase*) of Péwé's classification is vegetationally, as well as physiographically, a transition (Figures 6 and 7). It is found behind the White Spruce-mixed forest along the Kuskokwim River floodplain and on floodplains along the larger tributary rivers, such as the lower part of the Big River, Windy Fork, South Fork, North Fork and Takotna, but it is missing in the valley of the Nixon Fork. The change in vegetation involved in the transition is first indicated by the appearance of *Sphagnum capillaceum* and *S. Girgensohnii* in hollows in the White Spruce forest [14].

Then there is a gradual increase of *S. fuscum* and *S. rubellum* until they become as conspicuous as the woodland mosses, *Hylocomium splendens* and *Pleurozium Schreberi*. This is an important change. Correlated with it is the replacement of White Spruce and Birch by Black Spruce (*Picea mariana*). A dense shrub layer of such heaths as Blueberry, Labrador Tea (*Ledum groenlandicum*), and Hudson's Bay Tea (*Ledum decumbens*) and of Dwarf Birch (*Betula glandulosa* and *B. nana* var. *sibirica*) appears. The luxuriance of sphagnum growth increases in low places and on the edge of the forest toward the bogs it is very thick and loose. Along many of the bog margins there is a zone of transition where the forest is barely able to survive the wetness of the ground. The bogs in Phase III are formed by the swamping of low-lying areas or by the colonization of ox-bow and bar lakes.

The product of the change from White Spruce to Black Spruce is not the muskeg of an isolated bog. It is a tall, thick forest on the same level on the floodplain as the White Spruce-mixed forest, and not related to terrace forms of any sort. It is an expression of the increasingly wet soil conditions that develop under the present climate on the floodplain surface with the passage of time. The "developmental" relationship of the White Spruce-Black Spruce forest to the White Spruce-mixed forest is

14) Cajander (1913) describes *Polytrichum commune* as the first species to appear in swamping (*Versumpfung*) and Sjörs (1948) in his paper indicates that such is still the case in Scandinavia. In the Kuskokwim Region the lowland forests have a thick carpet of mosses already and so this species, a pioneer on barren ground, does not fill that function. Following *Polytrichum* in Scandinavia come peat mosses (*Sphagnum acutifolium*, then *S. fuscum*). Equivalent species in Alaska (*Sphagnum capillaceum*, *S. Girgensohnii* and *S. fuscum*) replace *Pleurozium* and *Hylocomium* in the lowland forest hollow.

indirect, via the change in soil conditions, in the same way that the relation of the river-bank willows to the poplar forest and to the spruce forest is not one of direct descent. This relationship is one of sequential occupancy of a surface, modified through time by influences in large part external to the vegetation.

Probably for related physiological reasons, on the relatively coarse-grained materials of the lower compound alluvial fans where the rivers are in a transition between the braided and meandering "habit", this same mixed forest of White and Black Spruce with a thick mat of *Hylocomium, Pleurozium* and *Sphagnum* is found. But while there is a sharp separation of the forests and drainage between Phase II and Phase III on the meander floodplain, on the mixed coarse and fine deposits of the lower compound alluvial fans, there is a broad zone of intergradation. The sharp transition on the floodplain may be for fundamental reasons that are not known, or it may be an illusion resulting from the fact that sloughs are rapidly colonized by Black Spruce and sedge or grassy swale vegetation when the water-level rises, which emphasizes the low areas in the topography. It is probably true, too, that the tolerance of White Spruce and White Birch to the depth of seasonal thaw is very sharply limited.

The vegetation as well as geological features suggests that the difference between Phase III and Phase IV is the product of a considerable age difference. The surfaces of Phase III are comparatively recently deposited by the river, while those of Phase IV were deposited many generations of meanders ago. Péwé has suggested that the history of Phase IV may differ in geological details.

Phase IV (*Scalloped Phase*) includes the oldest surfaces of the floodplain in the Upper Kuskokwim River Region (Figures 2, 7, 8, 9 and 22). It is covered with a thin and open forest of Black Spruce through which are scattered many small lakes and boggy hollows.

The ground is covered with a thick and continuous carpet of *Sphagnum fuscum* in which are patches of *S. rubellum, Hylocomium splendens* and *Pleurozium Schreberi.* A strong development of lichens (*Cladonia sylvatica, C. rangiferina, C. amaurocraea, C. gracilis, Cetraria cucullata, C. islandica, Peltigera aphthosa, P. canina,* and *Nephroma arcticum*) on hummocks and

dry places is characteristic of this forest. There is a dense shrub layer of heaths such as Blueberry, Hudson's Bay Tea, Leatherleaf (*Chamaedaphne calyculata*) and Dwarf Birch (*Betula nana* var. *sibirica*). The moss carpet is covered with Mountain Cranberry, Dwarf Cranberry (*Vaccinium Oxycoccos*) and Salmon or Cloud Berry (*Rubus Chamaemorus*). There are scattered White Birch trees, thickets of willows (*Salix pulchra, S. Bebbiana*) and alders (*Alnus crispa*) and a few Larch trees (*Larix laricina* var. *alaskana*). Black Spruce trees are about 20 feet tall and average 15—20 feet apart.

The best development of Phase IV is found: 1) between the Big River and Black Water Creek (Figure 1), 2) between the South Fork and the North Fork near Medfra (Figures 1 and 7), and 3) in the lowlands of Nixon Fork (Figures 1, 2 and 8). There is usually a sharp line of separation between Phase III and Phase IV at the limit of the zone of active meanders. Under the influence of active bog formation in the Nixon Fork swamp-plain, Phase IV seems to obliterate all but Phases I and II which are found on the natural levees (Figure 2). It is not until the lower part of the Nixon Fork, where it joins the Takotna that the transition, Phase III, is found.

Phase IV does not have a characteristic bog vegetation. Instead, bog vegetation reflects the characteristics of lake or depression without regard for the specific surface on which it is found. The lake-bogs may be of the nearly pure peat bog type, or of the combined influences of silt and peat.

The Black Spruce forests of Phases III and IV, with their heavy moss carpet, are the site of the development of most of the bogs. Permafrost is not necessary for the development of the Black Spruce forest, but in areas where permafrost occurs in the Upper Kuskokwim River Region, perennially frozen ground occurs under Black Spruce.

The Vegetation of the Bogs

Perhaps the most conspicuous characteristic of the bogs, after their huge size, is their vegetation pattern. Large areas are occupied by simple stands of sedges or low brush and one or two sphagnum species (Figures 10 and 11). The simple stands vary and shift from bog to bog, like the colors in a kaleidoscope and indeed

resemble the orderless pure stands which characterize the weeds in a fallow garden. But species occur repeatedly in the same associations. Other large areas are regularly patterned with clumps or ridges (Figures 14, 15, 18 and 21). In these areas there is a general meadow-like covering of sedges or low heaths growing in sphagnum and on it are superimposed patches and ridges of more mesophytic vegetation. The ridges form nets or festoons and are called *Strangmoor* in European descriptions.

SUCCESSIONAL SEQUENCE

There are degrees of consolidation and complexity of the bog vegetation which suggest successional sequences, although they can be shown not to be unidirectional. It is most convenient to describe the vegetation in terms of the various stages from open water to tall shrubs and to Black Spruce forest. Still or slowly moving water encourages the growth of immersed *Sphagnum* (*S. Lindbergii* and *S. Dusenii*), *Drepanocladus fluitans*, and sedges (*Carex rostrata* and *Eriophorum Chamissonis* var. *albidum*). Building of a tighter mat starts within the bog by growth and reproduction of mosses and sedges. Into this more compact, relatively more secure area, *Sphagnum balticum*, *S. recurvum* or *S. riparium* advance, and with them *Carex limosa*, *C. rotundata* and *C. chordorrhiza*. Next appear bog shrubs: *Andromeda Polifolia*, *Ledum decumbens*, *Vaccinium uliginosum*, and *Betula nana* var. *sibirica*. *Sphagnum papillosum* and *S. magellanicum* may appear at this stage. At this stage, patches or ridges of *Sphagnum fuscum* appear, and with them further development of heath shrubs with the addition of *Vaccinium Oxycoccos*, *Chamaedaphne calyculata*, and *Rubus Chamaemorus*. Trees, *Picea mariana* and *Larix laricina* var. *alaskana*, appear next and with them woodland mosses (*Hylocomium splendens*, *Pleurozium Schreberi*, *Dicranum scoparium*, *D. fuscescens* and *Ptilium Crista-castrensis*) between the hummocks of sphagnum. Other species of *Sphagnum* also appear (*Sphagnum capillaceum*, *S. Girgensohnii*, *S. rubellum*). Then on the drier forest floor, there is a proliferation of lichens (*Cladonia amaurocraea*, *C. gracilis*, *C. rangiferina*, *C. sylvatica*, *Cetraria cucullata*, *C. islandica*, *Peltigera aphthosa*, *P. canina*, *Nephroma arcticum*).

At the mesophytic end of the spectrum is the Black Spruce

NYMPHAEA TETRAGONA
RANUNCULUS GMELINI
HIPPURIS VULGARIS

CALLIERGON SPP
DREPANOCLADUS SPP
SPHAGNUM LINDBERGII
EQUISETUM FLUVIATILE
GLYCERIA SPP
CAREX AQUATILIS
CAREX ROSTRATA
POTENTILLA PALUSTRIS

CALAMAGROSTIS CANADENSIS
CAREX PHYSOCARPA

SALIX ARBUTIFOLIA
SALIX PULCHRA
BETULA GLANDULOSA

SALIX BEBBIANA
SALIX ARBUSCULOIDES
ALNUS CRISPA
ALNUS TENUIFOLIA

FLOOD PLAIN FOREST
HYLOCOMIUM SPLENDENS
PLEUROZIUM SCHREBERI
PICEA GLAUCA
BETULA PAPYRIFERA
RIBES TRISTE
ROSA ACICULARIS
VIBURNUM EDULE

SPHAGNUM OBTUSUM
SPHAGNUM SUBSECUNDUM

SPHAGNUM SQUARROSUM

SEDGE MEADOW
SPHAGNUM TERES
SPHAGNUM ÅNGSTRÖMII
SPHAGNUM RECURVUM
SPHAGNUM RIPARIUM
CAREX CANESCENS
CAREX MAGELLANICA
CAREX PALUDIVAGANS
CICUTA MACKENZIANA
GALIUM TINCTORIUM
GALIUM BRANDEGEI

HIGH BRUSH
CAREX TENUIFLORA
MYRICA GALE
BETULA NANA
BETULA GLANDULOSA
LEDUM DECUMBENS
CHAMAEDAPHNE CALYCULATA
VACCINIUM ULIGINOSUM

SPHAGNUM CAPILLACEUM
SPHAGNUM GIRGENSOHNII

MOAT
SPHAGNUM DUSENII
SPHAGNUM LINDBERGII
CAREX AQUATILIS
CAREX ROSTRATA

SEDGE MEADOW
SPHAGNUM BALTICUM
ERIOPHORUM CHAMISSONIS
CAREX CHORDORRHIZA
CAREX LIMOSA
CAREX ROTUNDATA

LOW BRUSH
SPHAGNUM PAPILLOSUM
SPHAGNUM BALTICUM
SPHAGNUM FUSCUM
BETULA NANA
ANDROMEDA POLIFOLIA
VACCINIUM ULIGINOSUM

MUSKEG
HYLOCOMIUM SPLENDENS
PLEUROZIUM SHREBERI
SPHAGNUM FUSCUM
SPHAGNUM RUBELLUM
LICHENS
PICEA MARIANA
LARIX LARICINA
ERIOPHORUM VAGINATUM
RUBUS CHAMAEMORUS
LEDUM DECUMBENS
CHAMAEDAPHNE CALYCULATA

BOG HOLLOW
DREPANOCLADUS REVOLVENS
SCORPIDIUM SCORPIOIDES
OR
HYPNUM BAMBERGERI
CAMPYLIUM STELLATUM
WITH
ERIOPHORUM ANGUSTIFOLIUM
CAREX CHORDORRHIZA
CAREX LIMOSA
CAREX LIVIDA
MENYANTHES TRIFOLIATA
UTRICULARIA INTERMEDIA
OR
SCIRPUS CAESPITOSUS
MYRICA GALE

HIGH BRUSH
MYRICA GALE
BETULA NANA
LEDUM DECUMBENS
CHAMAEDAPHNE CALYCULATA
VACCINIUM ULIGINOSUM

SILT SHORES

INFLUENCES
COMBINED

PEAT BOGS

FIGURE 13. VEGETATION ASSOCIATIONS. Associations of plants together that have been found consistently in the field are represented in sequence from wet to dry sites. There is no unidirectional development although on first examination the vertical columns seem to indicate such a tendency.

forest association of the old parts of the floodplain and most of the gentle hill slopes.

The processes involved are summarized diagrammatically in Figures 12 and 13.

Observations on the margins of the bog areas into which the forests are advancing indicate that there is a relative lowering of the water table. Bog ridges are closer together; the areas between ridges are drier and their vegetation of a less hydrophytic sort. The bog ridges are wider, and on them dense *Sphagnum fuscum* carpets can be seen to have grown over the sedge meadow (*Carex rotundata* and *C. limosa* growing in *Sphagnum papillosum*, *S. balticum*, *S. riparium* or *S. Ångströmii*).

Reforestation often occurs correlated with drainage of bog areas, as was observed in the northern part of the Nixon Fork lowland. At this place, migration of the river had led to drainage of a large bog and fire had further dried out the peat. There were still traces of the *Carex rotundata-Sphagnum balticum* and other bog types, but heath and birch shrubs were colonizing the whole surface. *Sphagnum fuscum* and seedling Black Spruce and Larch trees could be found on the margins and on low elevations.

Consolidation of the bog substrate probably proceeds as far as the development of patterns of sedge meadows, bog ridges and areas of heath and birch brush, then is held in a more or less stable condition until some change in geological conditions leads to a change in the vegetation. In other words, the vegetational process does not carry itself to completion and the return of the forest by itself. There has to be cooperation between botanical and geological processes. Such are the reasons that, vegetationally, the bogs are justly considered a stable element as they have been in northern Finland (Cajander, 1913). It is in the geological time-scale, concerned with aggradation of the major stream and advance of the bog margins by thawing, that the bogs repeatedly return to the forest condition and then the forests are re-invaded by bogs.

THE PLANT ASSOCIATIONS

The classification of vegetation used in the following discussion was developed in the field. Its initial categories are based on the plants' life form or aspect and under these categories associations are described floristically. No attempt has been made to

interpret the physiology of the component species or to discover indicator species in the sense used by European plant sociologists (Tansley, Braun-Blanquet, and Sjörs). The purpose of this section is to present a description of the bog vegetation as it has been observed in the field for someone who is not completely familiar with all the species.

An association is made of those species which flourish best under local microconditions of moisture, minerals and other habitat factors, whose seed source is available and which can replace other species. Thus the overlaps of species tolerances control the appearance together of certain species in societies, although there can be no doubt that certain species by their life and growth form exclude some species by competition or shading, and allow others to grow. The composite of species thus living together and not excluding each other is what is called an association or society. With this raw material the observer or describer fashions his own descriptive unit, called here an association.

Katz (1926), in his discussion of Russian bogs, presented an approach of this sort, which he illustrated in the following table.

CONCENTRATION OF MINERAL SALTS

MARSH 6-10%	TRANSITION BOG 5-6%	SPHAGNUM BOG 3.5-5%
PINUS SILVESTRIS		
BETULA ALBA		SCHEUCHZERIA PALUST:
ALNUS GLUTINOSA	CAREX LASIOCARPA	RHYNCHOSP: ALBA
CAREX LIMOSA		
CAREX ROSTRATA		ERIOPHOR. VAGINAT:
MENYANTHES TRIFOLIATA		LEDUM PALUSTRE
CALLA PALUSTRIS		CASSANDRA CALYC:
CAREX VESICARIA		
CAREX DIANDRA	MOLINIA CŒRULEA	
CAREX GRACILIS	CALAMAGROSTIS LANCEOLATA	
CAREX PARADOXA		
CAREX CAESPITOSA		
AULACOMN. PALUSTRE		
CAMPTOTHEC: NITENS	SPHAGN: SUBSICOLOR	SPHAGNUM MEDIUM
ACROCLADIUM CUSPID:		SPHAGNUM BALTICUM
DREPANOCL: VERNICOS:	SPHAGNUM RECURVUM	WARNS.

Taken from Journal of Ecology. 14 (1926)

Classification of vegetation on this basis emphasizes coincidence of requirements and deëmphasizes any assumption of intrinsic relations between the plant species requiring that they attain an equilibrium amongst themselves. This does not assume either that plant communities are purely random aggregations or that there is no relationship between species. The comparisons made later between Alaskan bogs and Scandanavian bogs argue against this. This vegetation cannot be considered under systems based on climax concept nor should it be rejected as weedy (Griggs, 1934). This problem is considered further in the Discussion.

Three major divisions of the vegetation of boggy and marshy places are made according to the conditions of the water table (Figure 13): 1) silt-bottomed, shelving beaches, 2) fully developed peat bogs with a high water-table, and 3) silt-shored ponds invaded by bog vegetation.

Fully developed peat bogs are similar to ombrogenous and soligenous mires of European workers, and similarly possess a flora poor in species. Their high water-tables are maintained by rainfall, stream flow, or groundwater flow.

According to strict circumscription, the vegetation of silt-bottomed, shelving beaches is not a part of the bogs system. However, wet sloughs or lake shores can be invaded by bog vegetation and become part of the bogs system as division 3 of this classification. Bog areas which have had this kind of history show the original beach flora and additional species typical of disturbed areas. The flora and individual species behave in the way that Anderson has described for *Iris* in the delta of the Mississippi (1949, esp. chapter on Ecological Basis).

The sequences of vegetation under the two main regimens active on the floodplain surfaces are diagramed in Figure 20. The left column shows the effects of bog expansion by thawing and formation of a quaking bog carpet by plant growth at the same time. The right column shows the filling of a slough with silt and coincident changes in shore plants. Figure 16 shows maps of the flats area most intensively studied. Map A, small scale, shows about half of the whole of the particular flats and on it are marked the portions enlarged in the others, on which are mapped the major vegetation types. The flats area is on Phase III of the floodplain and is modified by extensive slope-wash and alluviation from Roundabout Mountain and Candle Hills. Because

the scale is small, details of *Strangmoor* patterns have often had to be omitted.

Vegetation of Silt-bottomed, Shelving Beaches: Beach Vegetation

This concerns silt shores where there is gradual lowering of the ground-water table or filling by river-born silt. Such pond shores are characteristic of the deciduous and White Spruce-mixed forests of the young floodplain surface, Phases I and II. Most of the lakes are old ox-bow or bar lakes. Many such ponds, however, exist in dune hollows and similar depressions on terrace surfaces.

The vegetational zones on the beaches of these lakes are diagramed in Figures 12, 13 and 20. They are as follows:

1) shallow water vegetation, essentially floating;
   mosses: Calliergon cordifolium, C. giganteum, C. stramineum,
   Drepanocladus aduncus, D. badius, D. exannulatus,
   D. fluitans,
   Sphagnum Lindbergii.
   higher plants:
   Potamogeton epihydrus var. Nuttallii, P. gramineus
   var. maximus, P. natans,
   Nuphar polysepalum, Nymphaea tetragona,
   Ranunculus Gmelini var. yukonensis,
   Hippuris vulgaris.

2) shallow water vegetation, emergent;
   mosses: the same.
   higher plants:
   Equisetum fluviatile,
   Glyceria borealis, G. maxima var. grandis,
   G. pulchella,
   Carex aquatilis, C. rostrata,
   Potentilla palustris.

3) wet shores;
   mosses: the same with the addition of
   Sphagnum obtusum, S. squarrosum, S. subsecundum,
   higher plants:
   Calamagrostis canadensis,
   Salix arbutifolia, S. pulchra.

On the margins of this, next to the White Spruce-mixed forest, there are willow and alder thickets, most conspicuously *Salix*

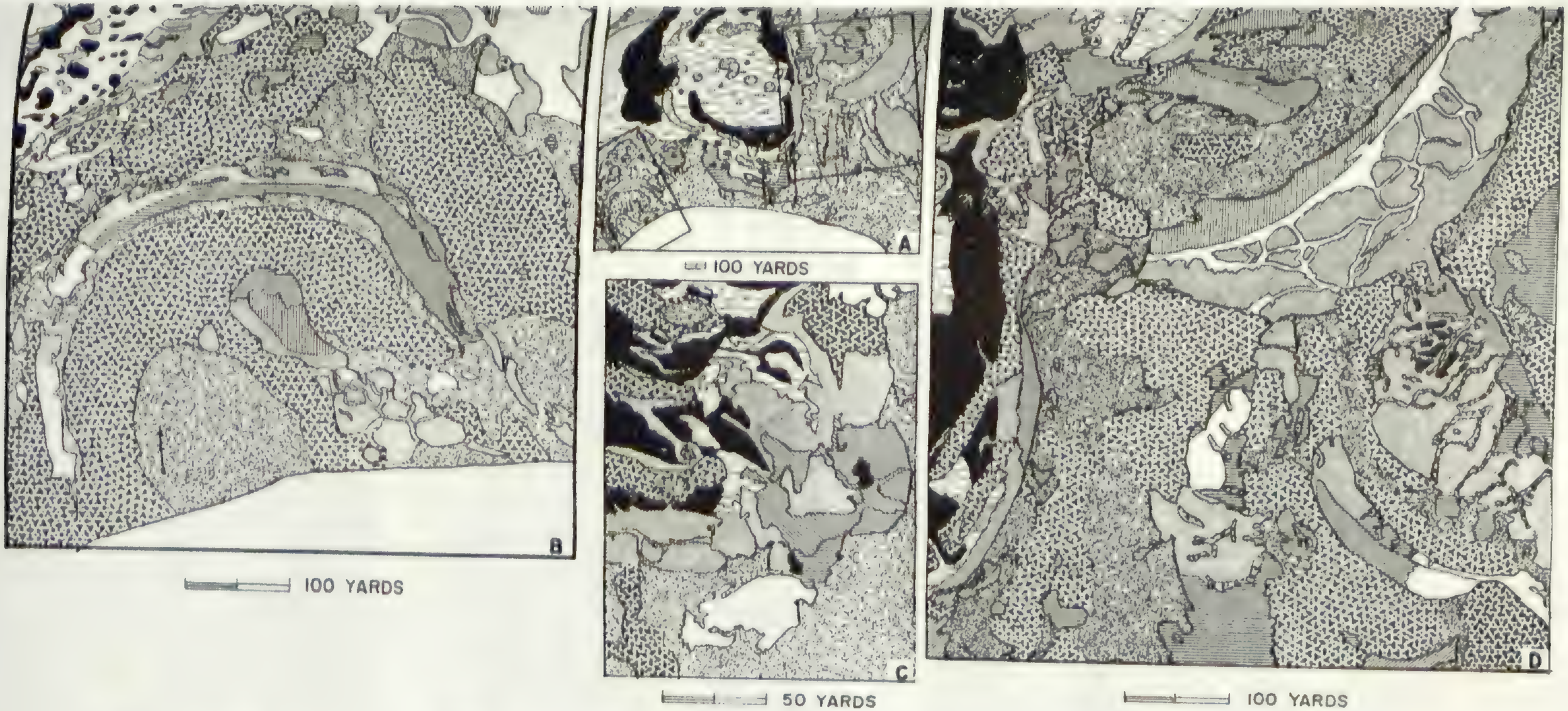

FIGURE 16. VEGETATION MAPS OF A FLATS AREA. These maps are of part of the bog area across the river, west of McGrath. The entire flats at this place is about three times the area shown in Map A. It is bordered on the North (right in Map A) by the Tatalina River, on the East and South by the Kuskokwim River and on the West by the slopes of Roundabout Mountain. On the small scale of these maps it is impossible to show details of bog ridge patterns. Areas of these (*Strangmoor*) occur on the top-left of Map B and at the top of Map A. Areas shown in black at the top-left of Map B and in the sedge meadows on the right of Map D are the wet centers of bog hollows.

Bebbiana and *Alnus tenuifolia*, but with scattered patches of *S. alaxensis*, *S. arbusculoides*, and *A. crispa*. Then finally there is the forest of the floodplain, whether it be White Spruce in pure stands, White Spruce-Poplar, White Spruce-Birch or a mixture of all three.

The zones are established primarily by extrinsic factors dependent upon the water-table. A rise of water-table will shift all the zones toward the wetter types and a lowering of the water-table or addition of silt deposits leads to colonization by less hydrophytic vegetation.

Vegetation of Peat Environments and High Water-Table: Peat Bog Vegetation

The water-table of peat environments is high and steady, and peat-forming mosses have invaded the stagnant or slowly moving water. The conspicuous development of *Carex* communities and the patterns of vegetation on valley slopes indicate, according to the Scandanavian studies, that there is a significant soligenous element to the bogs of the Upper Kuskokwim. The soligenous water (soil-water-flow) includes mineral elements not usually found in the rainfall collecting on the surface, which is the only source of water for a raised bog. The structure of soligenous mires is correlated with lower precipitation and more down-slope water movement. Changes in vegetation under the regimen of peat habitats are diagramed in Figures 12, 13 and 20.

For purposes of description, the vegetation of the peat bogs will be divided into three headings: 1) areas of relatively consistent simple stands; 2) areas of patterns of anastomosing bog ridges and intervening bog hollows; 3) areas where raised peat ridges form beaches along the edges of ponds and lakes. All of these occur in the bog area mapped in Figure 16.

Areas of relatively consistent, simple stand.

This heading is further subdivided into six categories: moats, hollows, sedge meadows, *Scirpus-Myrica*, low brush, and high brush. These are life-form categories as seen in the field, and in many bogs these simple stands occupy most of the surface. Although this vegetation has the weedy characteristic that it consists of large expanses of a few species, a regular internal structure is present, and species groupings are repeated with

regularity within the same bog, between bogs, and between areas.

The simple stands fall into three aspect types:

a) *Conspicuous vegetation meadow-like;* includes moats, bog hollows, sedge meadows, and *Scirpus-Myrica* areas.
b) *Conspicuous vegetation low heaths and Dwarf Birch shrubs,* not more than 6 inches high.
c) *Conspicuous vegetation of tall shrubs,* about 4 feet high.

In all cases, the associations may contain a moss carpet or have a mud bottom. In either case, the bottom may be firm or yielding, but in general the bottom is more dependable where there are shrubs, even though there may be a moss carpet that yields to a depth of two feet. Some sedge areas are nearly as firm as the sphagnum areas in Black Spruce forests; others yield to a depth of 4 feet. Where the sedge areas have a mud bottom, as in the bog hollows, they are especially insecure.

a) *Conspicuous vegetation meadow-like.*

1) The wettest areas of simple stands (which often are found in the moats) include *Carex rostrata, Carex lasiocarpa, Carex aquatilis* and a very few mosses, some *Calliergon, Drepanocladus,* and *Sphagnum Dusenii* and *S. Lindbergii* (Figure 10).

2) The next wettest areas have mud false-bottoms at about 3 inches and scattered emergent aquatics and sedges. They are shown in black on Map B of Figure 16 and those black areas in the sedge meadow in Map D. *Scorpidium scorpioides* and *Drepanocladus revolvens* occur scattered in the shallow water, as do *Carex limosa, Carex rotundata, Carex chordorrhiza,* and, less conspicuously. *Eriophorum angustifolium, Carex livida, Drosera anglica, Menyanthes trifoliata,* and *Utricularia intermedia.* In some places the bottom may be carpeted with *Campylium stellatum, Hypnum Bambergeri* and *Tricostenum cuspidatissimum* as moss layer; *Scirpus cespitosus* and *Myrica Gale* are characteristic of such a place, or *Scirpus* and *Myrica* with *Scorpidium* and *Drepanocladus.* These areas are called bog hollows here (*Flarken* or *Rimpi* by the Scandinavians) and are characteristic of the spaces between bog ridges in a *Strangmoor.*

3) Next, the sedge meadows are the driest of the meadow-like vegetation. They consist of *Sphagnum balticum,* or *S. Dusenii,* (*S. Dusenii* in wetter areas) with *Carex limosa, C. chordorrhiza, C. rotundata,* and less often *C. rostrata, Eriophorum Chamissonis* and *Carex paludivagans.* They are marked as sedge meadow in Figure 16.

b) *Conspicuous vegetation low heaths and Dwarf Birch shrubs.*

A firmer carpet is made by colonization by *Sphagnum papillosum*

or *S. fuscum,* heaths and Dwarf Birch. The first arrivals among the shrubs are *Andromeda Polifolia* and *Myrica Gale;* then *Betula nana. Vaccinium uliginosum* and, less often, *Chamaedaphne calyculata. Vaccinium Oxycoccos* is an abundant plant at this stage, but is inconspicuous because of its size. At the same time *Vaccinium Vitis-Idaea* and *Rubus Chamaemorus* appear. This type usually grows in a tight matrix of sedges and sphagnum. This is shown as low brush in Figure 16.

c) *Conspicuous vegetation of tall shrubs,* about 4 feet high (Figure 11).

The high brush areas become established coincident with *Sphagnum papillosum* and *S. fuscum* in which are growing shrubs of *Myrica Gale, Betula nana, Betula glandulosa,* often *Potentilla fruticosa, Ledum decumbens, Chamaedaphne calyculata, Andromeda Polifolia* and *Vaccinium uliginosum,* all about 3 feet high. Among these are a few Black Spruce and Larch. Following the thickening of the *Sphagnum fuscum* mat, a forest cover eventually is developed, if the water level has been lowered enough. This type is not mapped in Figure 16.

In many places where a shallow layer of water from a hillslope runs across the bog surface (*Überschwemmungsmoor*) the 4-foot shrub vegetation of *Scirpus-Myrica* grows with scattered mosses or no moss carpet. Large areas are like this at the heads and margins of streams that run through the bogs. This type is shown as flooded bog in the top left-hand corner of A, and at the top of D in Figure 16.

The bog surfaces at some distance from wet centers and especially bogs where there are no peat ridges have a very widespread high brush cover of heaths, *Myrica* and birch. These parts seem to have reached comparative maturity or stability of vegetation (a subjective impression). Near stream channels, moats, regressive areas or on "new" bogs, sedge meadows and low brush are found. The high brush type seems to converge with the brush tundra or wet tundra type of vegetation and may reflect an especial success of that life form and group of species. All across the north the heath-birch brush seems to be especially successful in and out of the forested areas and may represent the closest approach to a climax concept, at least as DuRietz (1936) uses the idea, developed first by Gams (1918), of considering vegetation by one-layered communities. Brush constitutes the stable bog vegetation until drying out allows occupation by *Sphagnum fuscum*-Black Spruce or further bog cycles invade the area.

Patterned Surfaces (*Strangmoor*)

Patterns of bog ridges are found in all parts of the bogs, but they usually are best developed at the upper ends, lower ends or

around the edges and away from central bodies of water. Their distribution seems to depend upon the presence of slope in the surface of the bog. There are two parts of the pattern, the bog ridges (*Stränge* or *Pounut*) and the areas between or bog hollows (*Flarken* or *Rimpi*).

Related to these nets in their vegetation and presumably in the physiographic process which creates them is a pattern of Black Spruce trees spaced as regularly as if in an orchard. The two patterns are discussed in the section about vegetation patterns on the bog surfaces. The patterns of both types, ridges and patches, show especially well on aerial photographs. The bog ridges may form into a net-like pattern (Figures 18, and 19 bottom diagram) or into festoons and parallel ridges like waves on the ocean (Figures 14, 15, and 19 top diagram). The festooning bog ridges are found in the wettest parts of the bogs. They "drag" against islands and "belly out" in the zone between. A large area of this type of bog ridges was found just at the top of Map A, Figure 16.

Bog ridges are more numerous and the bog hollows narrower on the margins and lower edges of bogs. In such places the pattern is often expressed as a net rather than as festoons. A net pattern is developed in the top left corner of Map B, Figure 16.

The bog ridges are narrow (often about a yard across although they may be ten or more) and may be several hundred yards long. The areas between (bog hollows) are wetter with less compact vegetation; often their centers are shallow, mud-bottomed pools with scattered emergent aquatics. They are often 30 to 40 yards across. The length of their long axis, like that of the bog ridges, depends on the bog in which they are found, because they often extend from shore to shore. The long axes of the bog ridges and bog hollows run across the slope or lie at right angles to the direction of flow of water. The bog ridges act as dams and resemble terracette margins, while the surface of the intervening bog hollow is level.

Although there is consistently a vegetational difference between the bog ridges and bog hollows, the difference is not always the same. The only safe generalization is that more mesophytic species of sphagnum, sedges and heaths occupy the ridges, more hydrophytic ones the hollows. There is a sharp segregation of species

Figure 15. etc.

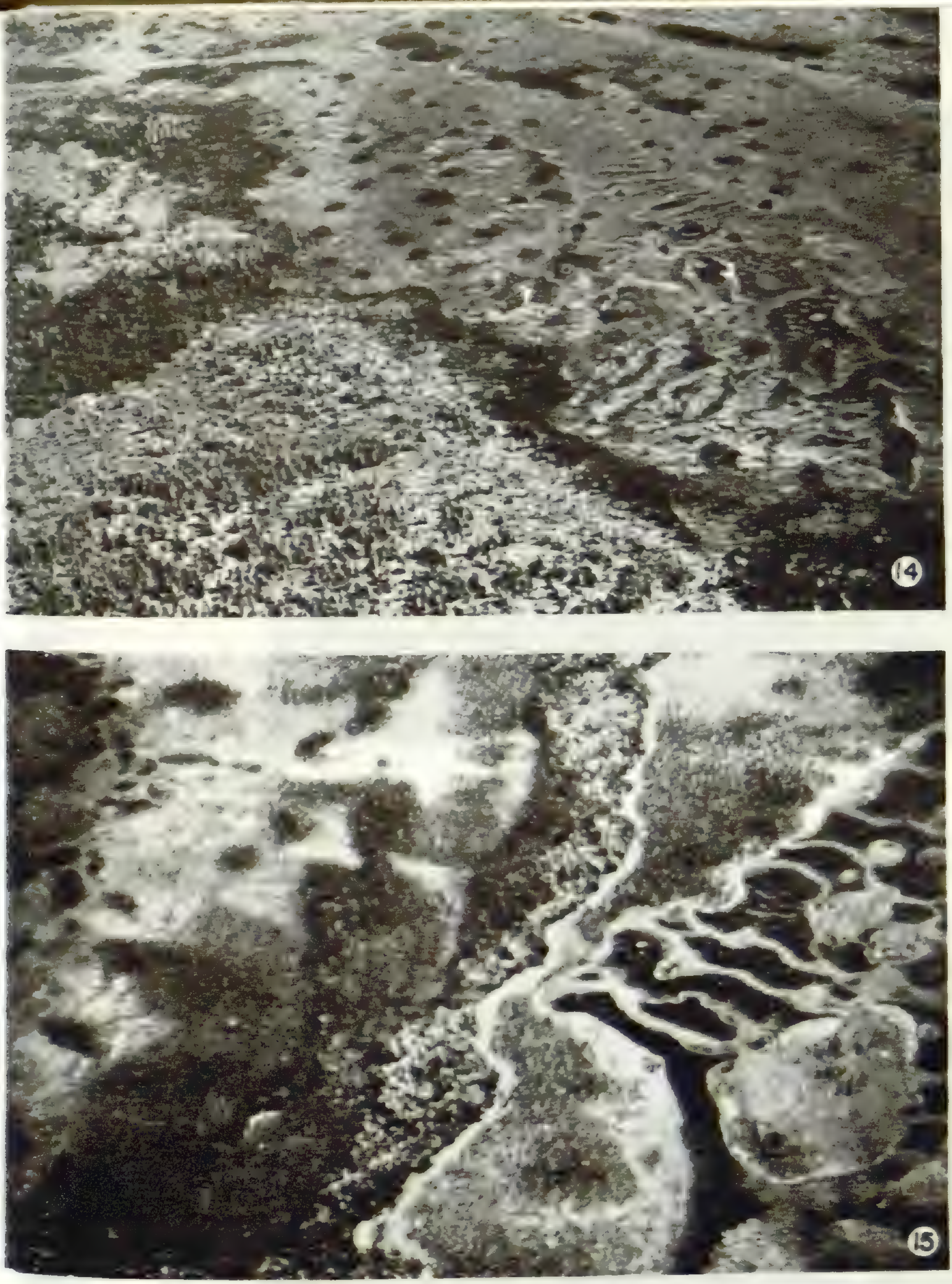

FIGURE 14. LOW ALTITUDE AERIAL VIEW OF BOG VEGETATION. Vegetation patterns expressed n this bog surface include both bog ridges and scattered clumps of trees. Notice the egularity of the distribution of the forested islands, the transverse arrangement of the ridges. nd the islands of vegetation forming in the water. The lowland forest shown includes spens, White Birches, White Spruce and Black Spruce. The bogs appear light in tone nd are bog brush and sedge meadows. The islands are of Black Spruce. Standing water ppears as the darkest tone. Photograph taken at about 1500 feet relative altitude in the kwentna area northwest of Cook Inlet, by A. T. Fernald.

FIGURE 15. LOW ALTITUDE AERIAL VIEW OF BOG VEGETATION. Bog ridges and initial clumps f colonizing vegetation are shown in the shallow water. A zone of coarse sedges on the edge f the forest appears. It resembles a 'moat' or '*Lagg*'. The thin forest on the upper left is Black Spruce. The dark forest tone running diagonally across the center of the photograph s White Spruce and White Birch. On the right of the coarse sedges is an area of bog rush and Black Spruce; the light tone near the standing water is sedge meadows. Photograph aken at about 400 feet relative altitude in the Skwentna area northwest of Cook Inlet, by A. T. Fernald.

FIGURE 17. FROZEN POOL AT ROCKPORT, MASSACHUSETTS, FEBRUARY 1952. The surface plan of ridges is similar to that of a net of bog ridges. Water rising through the outlet in the left foreground flowed diagonally away toward the figure in the background, freezing as it moved. There was no indication of the collapse of a temporary sheet of ice.

FIGURE 18 BOG RIDGES ON A STRANGMOOR. Bog ridges are shown on a sedge meadow in the bogs west of McGrath. The sedge meadow is very poorly consolidated and will support the weight of a man only briefly. A man's weight on one of the ridges causes all of the trees on that ridge to tip towards him. The packboard supplies scale. This picture was taken off the map, above and to the right of Map A, Figure 16.

involved. Only rarely is the pattern of the ridges due only to differential species abundance, which seems to be often the case with vegetation patterns such as rings and polygons in the tundra.

Occasionally, within a large scale pattern of bog ridges and hollows at the edges of bogs, there may be found a pattern of minor ridges across the long axis of the hollows of the larger pattern. This is described later.

Vegetation of bog ridge and hollow areas arranged in sequence from the wettest to the driest.

(a) *The wettest centers* of bog hollows (the *Braunmoor,* of Auer, mud bottomed or carpet vegetation of Sjörs [15]) have a sparse moss flora of *Drepanocladus revolvens* and *Scorpidium scorpioides;* usually *Utricularia intermedia* is consistently present, and, occasionally, a few plants of *Utricularia vulgaris.* The emergent vegetation is a scattering of plants or clumps about 10 inches apart growing in about 4 inches of water. The bottom is mud and yields to a depth of 4 feet, more in some cases. The most usual higher plants are *Eriophorum angustifolium, Carex livida. Carex limosa. Carex rotundata, Carex rostrata, Myrica Gale, Drosera anglica,* and *Menyanthes trifoliata.* Sometimes the centers contain *Scirpus cespitosus, Myrica Gale* and *Campylium stellatum.*

(b) *The margins of the centers (Weissmoor,* or carpet or lawn communities), are characterized by the presence of *Sphagnum Dusenii, Sphagnum recurvum,* or *Sphagnum balticum* and sedges whose decumbent stems and other underground parts weave together into a carpet, holding the sphagnum more firmly. Sedges found here are *Carex chordorrhiza. Carex limosa,* and *Carex rotundata.* Occasionally some of the elements of the wettest centers are important in this zone, and often there are scattered shrubs of *Andromeda Polifolia.* Less often *Betula nana, Ledum decumbens, Chamaedaphne calyculata* and *Vaccinium uliginosum* colonize from the drier sites. The shrubs are found as scattered individuals or in patches. Such patches are often marked by a difference in sphagnum also.

Into this zone *Sphagnum papillosum* often advances, and it may entirely replace the above *Sphagna.* Where this has happened, excavations show that *Sphagnum papillosum* has grown on top of the other species of sphagnum. The invasion comes about in two ways: 1) as a carpet advancing broadside among the sedge stems and leaving as primary *Carex rotundata* and *Carex limosa;* or 2) as clumps or tufts along with shrubs (*Andromeda Polifolia, Myrica Gale,* or less often *Vaccinium uliginosum* and *Betula nana*). Once the *Sphagnum papillosum* is estab-

15) These terms are included as examples of their application to Alaskan bogs. They will be discussed in the section comparing the bogs with Scandinavian researches.

lished, scattered plants of *Eriophorum Chamissonis. Drosera rotundifolia* and patches of *Sphagnum fuscum* and *Sphagnum rubellum* are found in it.

(c) *The bog ridge* in the area studied is usually a high brush (Auer's *Reisermoor* or *Bruchmoor* or Sjörs's hummock communities). The brush grows on moss ridges of dense *Sphagnum fuscum* with lesser amounts of *Sphagnum rubellum* and in some places *S. robustum.* They are superposed upon peat or dead mosses of the vegetation zones described in (a) and (b). With the *Sphagna* appear *Pleurozium Schreberi, Ledum decumbens, Chamaedaphne calyculata, Vaccinium Oxycoccos, Vaccinium Vitis-Idaea, Vaccinium uliginosum.* and *Rubus Chamaemorus.* With the above, but less extensively, there appear *Carex lugens, Geocaulon lividum, Betula nana, Drosera rotundifolia.* and *Empetrum nigrum.*

Lichens appear as the substrate becomes firmer and drier: *Cladonia rangiferina, Cladonia sylvatica. Cladonia amaurocraea, Cladonia cyanipes, Cladonia deformis, Cetraria islandica, Cetraria cucullata,* and *Nephroma arcticum.* Although they are relatively few in actual numbers of individuals, where they appear perhaps *Picea mariana* and *Larix laricina* are the most characteristic plants of these ridges.

In at least two areas, the ridges have included as their important element *Eriophorum vaginatum* with *Myrica Gale, Vaccinium uliginosum* and *Spiraea Beauverdiana.* One such area is illustrated in the top diagram in Figure 19.

The two diagrams in Figure 19 are included as examples taken from field notes of how the vegetation types just discussed fit into a *Strangmoor* pattern. The notes were taken around the lake west of McGrath. The upper diagram is part of a long continuous bog nearly one mile long crossed by bog ridges 100—125 yards long and 15—25 yards apart. The bog ridges are 5 yards across, 2 feet high and support a few Black Spruce and Larch. This area is just at the top of Map A, Figure 16.

The wet centers are *Carex limosa, Carex paludivagans,* and *Menyanthes,* often with scattered individuals of *Eriophorum angustifolium, Carex livida* and *Myrica Gale.* The wet meadows in these areas consist of *Sphagnum Dusenii* (or *S. balticum* or *S. pulcbrum*), and *Carex limosa* with the following secondary species: *Calliergon* sp., *Sphagnum compactum, Eriophorum angustifolium, Scirpus caespitosus, Carex pauciflora. Carex chordorrhiza, Carex rotundata, Carex rostrata, Scheuchzeria palustris. Myrica Gale,* and *Drosera anglica.* The bog ridges have a sphagnum matrix of *Sphagnum papillosum* or, in part of the area illustrated, *Sphagnum balticum* and *S. fimbriatum.* The bushes are *Myrica Gale, Spiraea Beauverdiana,* and *Vaccinium uliginosum.* There are the fol-

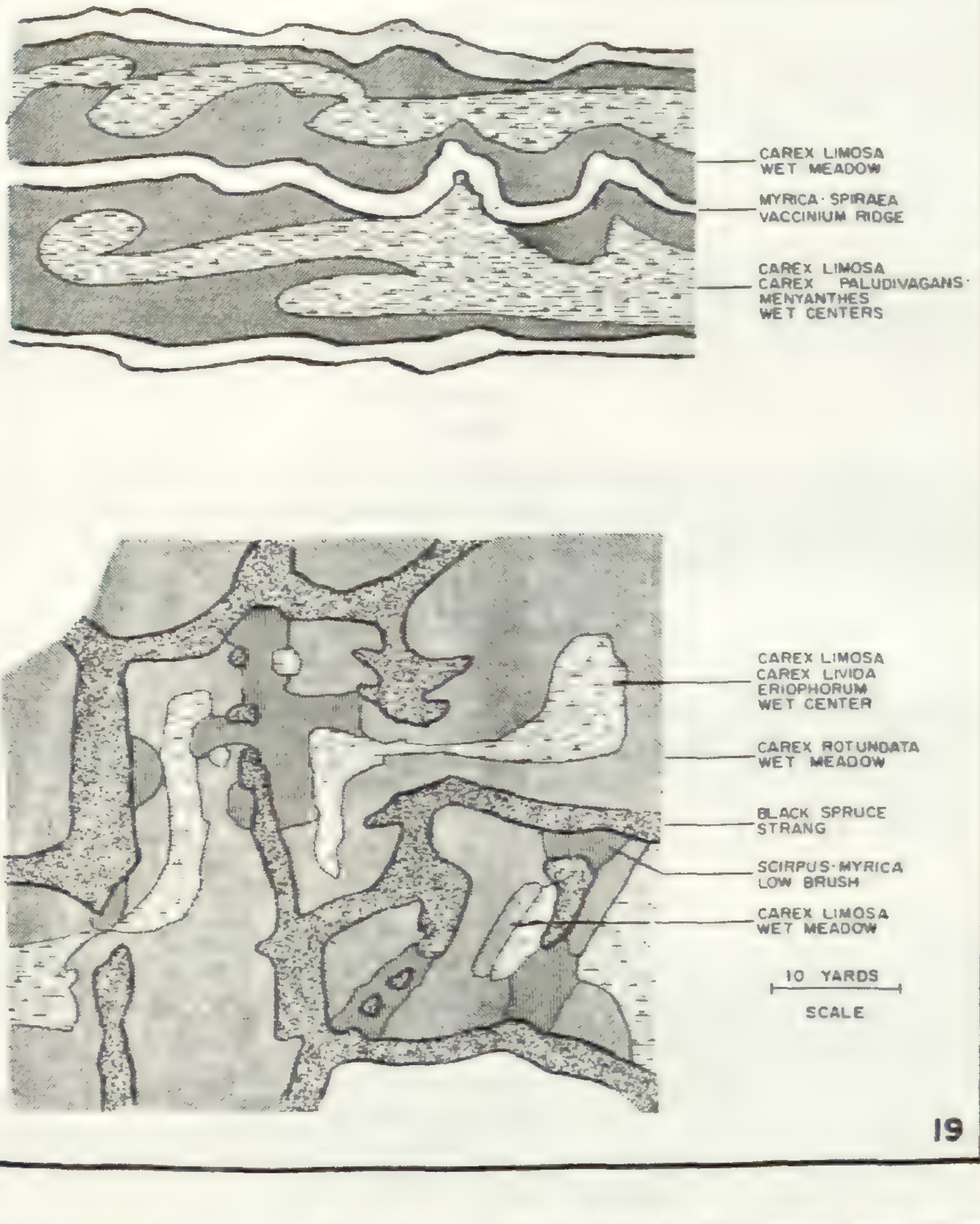

FIGURE 19 VEGETATION MAPS OF BOG RIDGE AREAS. The upper map represents the wettest part of a sloping bog such as those in Figure 15. This is a field map made at the bog area at the top of Map A. Figure 16 Water flows from the bottom to the top of the map. Dislocation of the ridges and peninsular growth of the sedge meadows are shown. In the lower map down-slope movement of water is to the left. The map was made at the upper left part of Map B. Figure 16. This area is at the side of the flats; water movement is at a minimum and many bog ridges have formed at various angles to each other.

lowing secondary species: *Aulacomnium palustre, Sphagnum robustum, Sphagnum recurvum, Picea mariana, Larix laricina, Eriophorum vaginatum, Betula nana, Drosera rotundifolia, Rubus Chamaemorus, Chamaedaphne calyculata,* and *Vaccinium Vitis-Idaea.* In some wet spots, the ridges are built of *Sphagnum fuscum, Eriophorum vaginatum* and *Andromeda Polifolia,* and locally *Ledum decumbens* and *Vaccinium Oxycoccos* are secondary species.

The lower diagram in Figure 19 was taken from a net-pattern southeast of the lake west of McGrath, in the top left-hand corner of Map B, Figure 16.

a) Wettest centers (*Rimpi* or *Braunmoor* of Auer; have the elements of both mud bottom and carpet communities of Sjörs).
Eriophorum augustifolium
Carex limosa
Carex livida

b) The most widespread vegetation of the centers also occurs as a concentric ring around the wet holes and inside the ridges:
(*Weismoor* or sedge meadow, a lawn community).
Sphagnum papillosum
Sphagnum balticum
Carex rotundata

c) The ridges are here expressed as stringers of the Black Spruce forest, (*Bruchmoor* or hummock community).
Sphagnum fuscum
Pleurozium Schreberi
Eriophorum vaginatum
Ledum decumbens
Chamaedaphne calyculata
Picea mariana

d) Wet *Scirpus-Myrica* area which in many places replaces b) type (included in *Weissmoor* or lawn communities).
Sphagnum papillosum in clumps
Scirpus cespitosus
Myrica Gale

e) Wet sedge meadow: occupies the margins of a) and may replace b) or d) in the pattern.
Sphagnum papillosum
Sphagnum balticum
Sphagnum Dusenii
Carex limosa

In a considerable part of the area the pattern lacks the a) type. The margins of *Strangmoor* areas toward the forest and away from open water tend to lack it while those nearer to the lake or open water show it.

Long avenues of sedge meadows exist near the margin of the

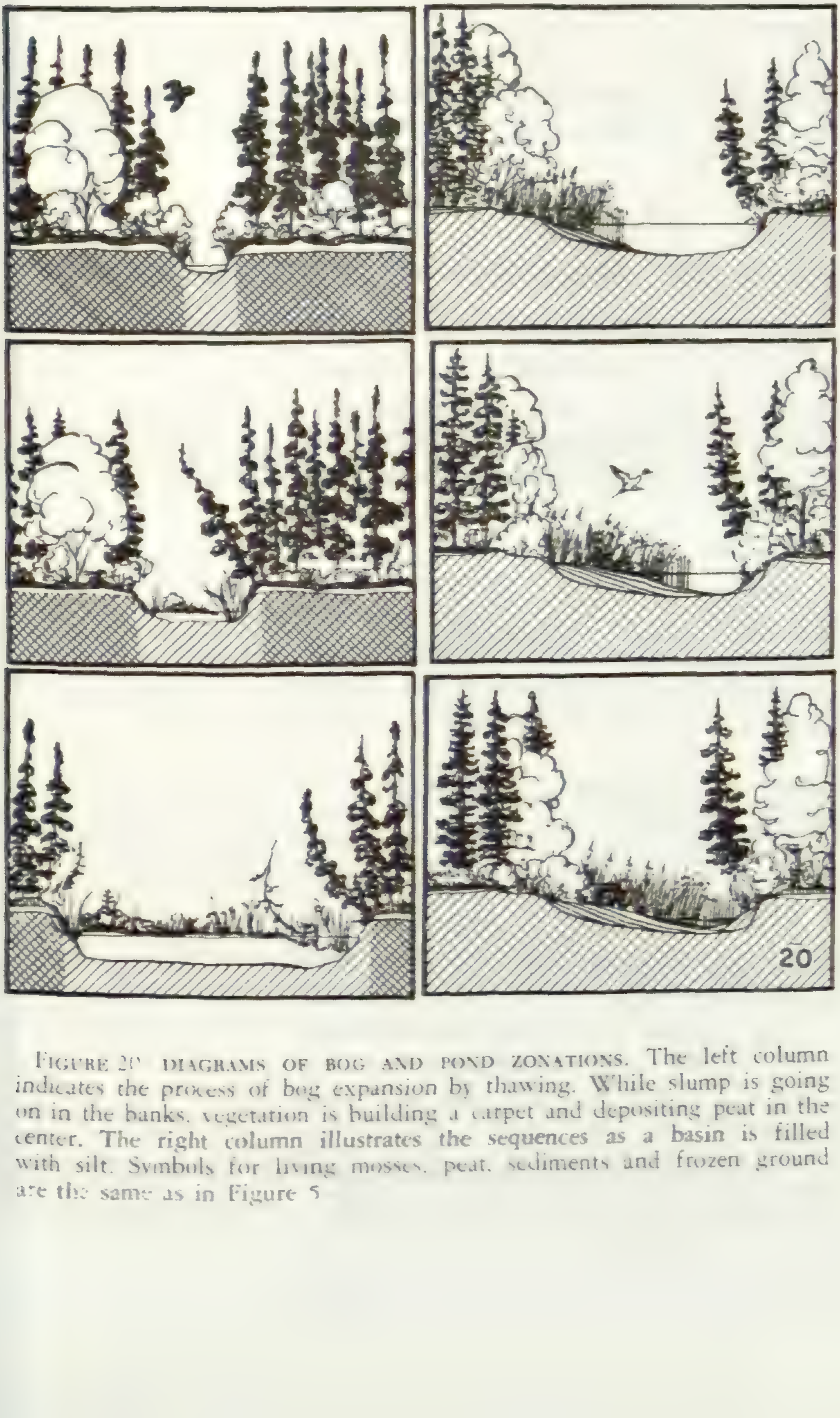

FIGURE 20 DIAGRAMS OF BOG AND POND ZONATIONS. The left column indicates the process of bog expansion by thawing. While slump is going on in the banks, vegetation is building a carpet and depositing peat in the center. The right column illustrates the sequences as a basin is filled with silt. Symbols for living mosses, peat, sediments and frozen ground are the same as in Figure 5

Strangmoor across which a small pattern of ridges has developed at right angles to the long axis of the meadow. One of these may be seen at the center of the top of Map B, Figure 16. The ridges of the large pattern are about one yard across, 6 inches high and 25 yards apart. The meadow is *Carex rotundata, Sphagnum balticum* and *S. papillosum*. The transverse ridges are *Sphagnum fuscum, Betula nana, Rubus Chamaemorus, Andromeda Polifolia* and *Vaccinium uliginosum,* with lesser amounts of *Ledum decumbens* and *Chamaedaphne calyculata.*

Raised peat ridges forming beaches lining open water

Wind-driven waves pounding against the edge of the pliable bog carpet, or the drifting ice in spring (after the thaw has freed the main mass from the shore) raise beach ridges. In some cases, these ridges are large and support Black Spruce trees; in others they are most noticeable in the change of vegetation and the sharp drop of the shore at their edge. Their vegetation is, as would be expected, a telescoped transect of the wet-dry sequence. The ridge often has a few Black Spruce or Larch trees, alder bushes and the vegetation of a bog ridge. The margins show *Sphagnum Lindbergii, Sphagnum Dusenii, Equisetum fluviatile, Carex limosa, Carex chordorrhiza, Myrica Gale,* and *Menyanthes trifoliata;* that is, the plants of wettest environments.

Vegetation of Areas Under the Combined Influence of Silt and Peat

Bogs of this type appear closely correlated with Phase III of the floodplain. Examples are shown in Figure 16. It is suggested that vegetation originally became established on the shelving silt shores of a pond or lake. Later the pond became invaded by peat bog forming vegetation which clogged the outlets and impeded the drainage system. Such lakes show vegetation largely of peat bogs, but also traces of vegetation which became established on a silt shoreline. The influence of the minerals in the silt is still effective because the peat-forming vegetation is so thin.

The amount of silt shore vegetation in the bog is a measure of the conditions at the time of invasion by bog flora or the shallowness of the bog. Because over most of its area this type of bog results from the occupation of relatively deep water, the

carpet of mosses, sedges and grasses is usually very loosely woven and yields to great depths.

The vegetation of these areas is divisible into three headings: ox-bow bogs, pot holes, and Aspen-lined pools.

Ox-bow bogs show best the characteristics of the rich flora of disturbed areas and are vegetated by large stands of relatively simple types. These are indeed weedy in the real sense of the word. Where these bogs are found close under the terrace escarpments, there are often a number of islands formed by slumping from the terraces. These are vegetated by *Pleurozium Schreberi*, *Calamagrostis canadensis* and *Betula papyrifera* var. *kenaica*. There is often strong indication that the edges of these bogs are invading the floodplain forest and killing off the trees by the swamping process.

Pot-holes and the bogs that occupy them are circular, oval or oblong areas that have developed in the midst of the forest of Black Spruce in natural hollows or as a result of thawing. Initially they are not connected with the main channels of the "flats", although many evidently have been subsequently invaded by the advancing- margins of the bogs. The flora of pot-holes is characteristically that of an invaded ox-bow or bar lake with emphasis on *Sphagnum obtusum*, *Sphagnum subsecundum*, *Sphagnum squarrosum*, *Calamagrostis canadensis* and *Carex physocarpa*

The term "*Aspen-lined pools*" is used for the depressions occupied by a pond more or less overgrown with vegetation and surrounded by a narrow ring of Aspen trees on the beach ramparts. Such groves and pools are common features of the Black Spruce forests between the dunes or erosional remnants on the terraces south of McGrath. The ground under the Aspen groves has no permafrost to at least 4 feet, which is also true of the bogs that have invaded the ponds. The surrounding Black Spruce muskeg, however, may be frozen at a depth of 18 inches in August.

Under present conditions these Aspen-lined pools are largely being drained by regional lowering of the water table, and for this reason most have the familiar silt-shore zonation: *Equisetum fluviatile* — *Carex rostrata* — *Glyceria*, *Calamagrostis canadensis*, and Dwarf Birch — heaths. Some, on the other hand, have become involved in drainage channels, since they are largely features of small valleys and interdune areas. These channels have become choked with bog vegetation, and the shore-line zones modified

by the colonization of the peat-forming species. Once peat bog vegetation has invaded a minor channel it often starts to destroy the channel banks and expand laterally, engulfing the surrounding Aspens and then the Black Spruce forest. By this process the flats have invaded and come to occupy much of the interdune areas between Blackwater Creek and Middle (Pitka) Fork. These invasions produce bogs that over large areas are purely of the peat bog type and that in other places are a hybrid of the peat bogs with old ox-bow bogs. These two influences are clearly expressed in bog areas examined at the mouth of the Middle Fork.

The sequence of events just described has allowed bog systems to advance up drainage channels, expand on new surfaces, and incorporate into the regional bog systems both floodplain and depositional slope surfaces of quite different physiographic age and history. For this reason, regional bog types discussed in this paper cannot be correlated with physiographic provinces more particularly than the general term alluvial lowlands.

Comparison of the Bog Vegetation with Scandinavian Studies

GENERAL COMPARISONS

The flora and vegetation of the bogs in the upper Kuskokwim correspond closely to the flora and vegetation of the bogs in the boreal or subarctic parts of Europe around the Baltic and in Russia (Cajander, 1913; Auer, 1920; Katz, 1926; von Post, 1937; Tansley, 1939; Sjörs, 1948). The bogs seem to be a combination of the soligenous and ombrogenous mires of the Swedish system (von Post, 1937; Sjörs, 1948) and correspond to the type of bog found in Europe in northernmost Sweden and Finland, north of the *Hochmoors* and intermediate types of southern Scandinavia and farther south. Unfortunately, nearly all of the European studies so far published have been made in regions where the vegetation is of a less northern type than that studied in the Upper Kuskokwim River Region.

Cajander (1913) separated the bogs of Finland into three major types according to natural plant groupings. The most northerly type, which he called the *Aapamoor* complex (Finnish, *Aapasuo*), was then as now the least well-known. The bogs of the Upper

Kuskokwim River Region correspond most closely to this type. Cajander's definition of the *Aapamoor* complex in general terms is translated below. Bracketed insertions are mine.

"I. It is a bog type of huge areal extent, whose borders can scarcely be recognized except where they join to the tundra. Bogs anastomose widely.

"II. There is characteristically a greater development of open bogs rather than forested bogs. The latter are very scarce.

"III. The open bogs are full of wet areas, rimpis, which often appear in more or less regular patterns separated or outlined by sinuous ridges, strangs.

"IV. Only exceptionally is there a high central area from which water flows outward [as it does in a *Hochmoor* type]. Water flow is nearly always unidirectional and can therefore have great force. [Equivalent to soligenous mire of Sjörs, 1948].

"V. The regional bogs are made up of innumerable original bogs which have coalesced by transformation of intermediate areas [swamping, or *Versumpfung*] which, then, are of younger age. The intermediate areas may undergo as great transformations as are found in bog complexes of other types. but the open, most common areas, the proper *Aapas,* seem stable. Variations in development [toward firm vegetation mat] and retrogression [towards hollows] are common enough in the centers.

"VI. The bogs correspond in distribution to the area of a thin forest found on peaty, partly mineral soil (*Rääseiköt* or *Vesikankaat*)."

Cajander remarks that bogs of a similar sort, characterized chiefly by the conspicuous development of bog hollows (he calls them *Rimpis*) are circumpolar. He mentions Iceland and the Faroes.

Von Post (1937) classified Swedish bogs on the basis of the physiological and peat-forming processes involved in their formation. This classification does not include the Aapasuo type of bog, and I have found it less useful than the classification proposed by Cajander (1913). In the most recent studies (Sjörs, 1948), the vegetation in the Swedish bogs is classified on the basis of "indicator species". Indicator species show marked physiological requirements, such as pH and mineral content, and they are used to label vegetation associations in the Scandinavian-Montpellier systems of plant sociology. According to this system, for instance, all species of *Carex* (except *C. limosa*), *Eriophorum angustifolium*, and *Menyanthes* are indicators of non-peat-bog

influence or the presence of mineral soil water. Furthermore, when the Scandinavians refer to a community rich in species, such as Sjörs Alliance *Scorpidion*, they mean rich in indicator species without regard for the total number of species present.

Most Scandinavian bogs are found in recently glaciated regions or on fresh glacial deposits derived largely from acidic or crystalline bedrock. The Scandinavians are not concerned with bogs that are extensive on fine-grained alluvium, like the Alaskan bogs. In addition, the Alaskan bogs have formed on alluvium which has been derived in large part from limestone or limey bedrock. For this reason, classification of Alaskan bogs according to the European system — topographic bogs (topogenous), rainfall bogs (ombrogenous), and soil water bogs (soligenous) — is difficult. The bogs of the Upper Kuskokwim River Region rarely show pure "moss bog" structure, presumably as a result of four factors: the lime content of the underlying silt deposits, the temperature, the amount of rainfall, and lack of any real topographic bogs. All of the bogs are under the control of through-soil movement or percolation (soligenous), and do not show true *Hochmoor* structures. For these reasons, sedgy areas are more conspicuous in Alaska. These are close to the fens of the Scandinavians (Sjörs, 1948), but not the fens of the English (Tansley, 1939).

Within the bog complexes Cajander (1913) recognized bog types as *Weissmoor*, *Braunmoor*, *Reisermoor*, and *Bruchmoor*. The bog types of the *Aapamoor* complex are chiefly of the *Weissmoor* type with some development of *Reisermoor*. This means that the bogs are mostly sedge meadows with some heath-covered areas. It is hard to understand exactly what Cajander's bog types mean without actual experience in the field. Certain Alaskan vegetation types considered in this paper have been found in all three major physiological divisions of Cajander's system (*Weissmoor*, *Braunmoor*, and *Reisermoor*). Sjörs divides bog vegetation into communities: mud-bottomed, carpet, lawn and hummock. According to his system the Kuskokwim bogs are chiefly lawn communities with some mud-bottomed and carpet communities in wet areas and some hummock communities in dry areas.

It is impossible to resolve a number of inconsistencies that appear, but these are probably the result of different bases of

classification. A comparison of plant communities in the field in both areas would contribute much to a consideration of the real nature of plant associations. Furthermore, the physiology of individual plant species probably varies between Scandinavia and Alaska. Different amplitudes produce different areas of overlap in optimal requirements and thus different species combine to form new associations; for instance, the combination of *Scirpus cespitosus-Sphagnum papillosum* (fen communities, mire expanses, and lawn communities) is unusual in the Upper Kuskokwim (although it is found with *Carex rotundata*, *C. limosa* and *Myrica Gale* in meadows in *Strangmoor*), but forms an important part of the fens described by Sjörs. There are extensive areas of mud-bottomed *Scirpus cespitosus-Myrica Gale* communities in the Upper Kuskokwim Region which Sjörs does not even mention.

The real problem probably lies with the expectation that associations will be identical in these two areas. This subject will be discussed later, but it is sufficient to say here that this expectation seems gratuitous, growing out of an assumption that a plant association has a pseudo- or quasi-organismic identity, that its integration requires its members to occur together. The contradictions which appear if the vegetation is analysed on a plant sociological basis disappear when it is regarded from an individualistic point of view (Gleason, 1926).

On the other hand the overall characteristics of the bog complexes in Scandinavia and Alaska are identical, and many of the species are identical. Cajander lists 84 conspicuous species that grow in bogs in Finland, 60 of which are found in the Upper Kuskokwim. In addition, 8 of the 16 species found in forested regions in Scandinavia are also found in forested regions in the Upper Kuskokwim. These 100 Scandinavian species are the primary species, the most conspicuous in the society. Similarities between the two floras diminish when secondary species are considered. A comparison of secondary species between three of Cajander's bog types (*Weissmoor*, *Braunmoor*, and *Reisermoor*) and Alaskan bogs shows 121 identical species and 164 dissimilar. However, I have been unable to find an Alaskan equivalent of *Braunmoor* (if I understand *Braunmoor* correctly), and if these species are eliminated from consideration there remain 109 identical species and 124 dissimilar. The *Bruchmoor*, the most

mesophytic bog type, shows an additional 34 identical species and 102 dissimilar species, emphasizing the point that as one gets away from the characteristic conditions of the open bogs the similarities diminish. This indicates very strongly that we are dealing with the same phenomenon in two areas. The surface expressions and the primary species are the same. When we consider the "specialties", less successful in the widespread vegetation — the plants that require more mesophytic or special calcareous conditions — the inter-continental differences appear. The primary species in the bog are highly successful in Finland as in Alaska; they are the circumboreal species, and this is another illustration of the familiar experience that the great mass of boreal vegetation (those species with large numbers of individuals) is remarkably uniform.

SPECIFIC CORRELATIONS OF VEGETATION TYPES

The emergent vegetation, sedge and grass, on the shelving silt beaches of ox-bow lakes, corresponds to fen communities as Tansley uses the term and to those fen communities of the Scandinavians which are found on lake and river shores.

The vegetation of peat areas as classified in the field is in many ways out of step with the Scandinavian classifications but the evidence of similarity of major types is clear to anyone familiar with bog vegetation.

Simple Stands

Areas of relatively consistent, simple stands consist of sedge-meadows, low brush and high brush.

a) *Low sedges in a meadow-like area* are fens of the Scandinavians or *Weissmoor*.

1) The wettest areas (coarse sedges) resemble British fen vegetation in the presence of coarse sedges and are similar or identical to the *lagg*. The *lagg* of Scandinavian bogs is occupied by a fen community of coarse sedges which show strong mineral soil influence. These correspond to the vegetation of the moats. Sjörs (1948) describes fen carpet communities similar to those that have a wide distribution on margins of regional bogs. He describes them as topogenous (such as bar lakes) and limnogenous (edge of lake) fen sites subject to repeated inundation. The edges of bogs in the Upper Kuskokwim River Region which are next

to stream courses are occupied by a similar vegetation, and on the edges of lakes this tall sedge type may include *Sphagnum papillosum* (site near Lone Mountain) thereby approaching the Scandinavian type even more closely.

2) The next wettest sites, (typical bog hollows) have mud bottoms, scattered emergent aquatics and sedges. They are referable to Cajander's *Rimpis*, or are close to his *Braunmoor*. Perhaps only the *Scirpus cespitosus-Myrica Gale* and the *Scorpidium scorpioides-Carex livida* types should be classified as *Braunmoor*. Even the last can be correlated with samples Cajander included in *Weissmoor* and Sjörs in fens (Swedish *Kärrsamhällen*, German *Flachmoorgesellschaften*). *Braunmoor* is characterized by the presence of *Drepanocladus-Scorpidium*, and no *Sphagnum;* it is calcicolous. It may be that in the Upper Kuskokwim River Region the only places where the calcicolous tendencies in the alluvium derived from limey bedrock show through are in those bogs that are nearly free of mosses because any peat concentration creates acidic conditions. These wet mud-bottomed sites correspond, according to the details of their vegetation, to Sjörs's mud-bottomed communities (*losbottensamhallen*) if indicator species *Utricularia* sp., *Carex chordorrhiza* and *Drosera anglica* are present, and to carpet communities (*mjukmattsamhallen*) if indicator species *Scorpidium scorpioides*, *Carex limosa* and *Carex livida* are present and *Carex chordorrhiza*, *Utricularia* and *Drosera* absent.

All of the indicator species which Sjörs uses to separate the two communities occur together in Alaska in mostly mud-bottomed areas in the wettest parts of the bogs. These places are usually old lakes, and there are no ridges developed.

3) Sedge meadows seem to correspond to *Weissmoor* of Cajander and some of the fens of the Scandinavian literature, but not the fens of the English writers.

The closest to this in Sjörs's classification is the lawn community (*fastmattsamhallen*) with indicator species *Myrica Gale*, *Eriophorum vaginatum*, *Sphagnum balticum* and *S. papillosum*. When sedge meadows are combined with areas of low brush as they are for example in some parts of the bogs west of McGrath they correspond closely to *Weissmoor* and lawn communities.

b) *Low heaths and Dwarf Birch* in *Sphagnum balticum* or *S. papillosum* are not separated as communities as such by the

Scandinavians. They seem to correspond to *Weissmoor* and lawn communities.

c) *Dense brush up to four feet high* growing in sphagnum on an open bog corresponds closely to the *Reisermoor* of Cajander's classification. Where Black Spruce colonizes, the brush growth is usually looser and corresponds to the Scandinavian *Bruchmoor*. These both seem to correspond to Sjörs's hummock communities (*Ristuvsamhallen*) with indicator species *Vaccinum* spp., *Empetrum* sp., *Betula nana* and *Sphagnum fuscum*.

The tall heath communities with a dense Sphagnum carpet relate those bog areas to ombrogenous mires.

Areas of brush which are mud-bottomed and vegetated with *Scirpus cespitosus-Myrica Gale*, giving the impression in the field that they are subject to repeated floods, are equivalent to Scandinavian *Überschwemmungsmoor* and similar types are considered as important in soligenous mires by Sjörs.

Small open ponds occur in the Alaskan bogs as well as in those in Scandinavia (*Kölke*). Their presence and the processes producing them are sufficiently complex to offer material for a separate study.

Patterned Surfaces

Patterned surfaces consist of islands of mesophytic vegetation or the bog ridge-bog hollow complex. Vegetationally the islands are identical with bog ridges.

Bog ridges are called *Stränge* in German, *Strangar* in Swedish, and *Pounut* in Finnish; Auer refers to the word *Revel* without indicating source. The ridges can usually be put into one of two categories: a) low brush associations which correspond to lawn communities of Sjörs and in part to *Weissmoor* of Cajander; b) high brush which corresponds to Sjörs's hummock communities or to *Reisermoor*. If there are scattered trees they correspond to *Bruchmoor*.

The wet centers or bog hollows are called *Flarken* in German, *Flarke* in Swedish, *Kulju* or *Rimpi* in Finnish; again Auer, without source, refers to *Dykarr*. The hollows in their wettest portions correspond to mud-bottomed communities and carpet communities of Sjörs and *Braunmoor* of Cajander. The sedge meadow centers and low brush margins correspond to carpet or lawn communities in Sjörs's system or *Weissmoor*.

The low brush areas which are common and often a conspicuous

part of the pattern between wet centers and ridges in Alaskan bogs are not reported to be of such general distribution in the Scandinavian *Strangmoor*. The absence of this community as a conspicuous part of *Strangmoor* vegetation may account for the ambiguous position of *Weissmoor* and lawn communities. The sedge meadows and low brush types seem to occur together as one community in Scandinavia instead of in two parts, as in Alaska.

Examples of these communities as they are found in the field are included with their equivalent European names in the description of the vegetation under *Strangmoor*.

The combined influence of silt and peat

The large areas of the loosely compacted sedge meadows under these mixed conditions are equivalent in composition and aspect to *Weissmoor* or lawn communities. The tall brush areas correspond to *Reisermoor* or hummock communities. But mud-bottomed communities and carpet communities rich in species that Sjörs calls Alliance *Scorpidion* both occur. The Black Spruce forest of alluvial lowlands and depositional slopes corresponds in form to what the Finnish writers (Auer, 1920; Cajander, 1913) refer to as *Bruchmoor*, *Reiser-Föhrenmoor*, or especially "*Anmoorig Wald*". It seems to correspond in form also to what is called *Rääseiköt* or *Vesikankaat* in Finnish. *Bruchmoor* is a swamp forest. *Reiser-Föhrenmoor* is an open stand of stunted Pines (*Pinus silvestris*) on a heath bog, which probably corresponds to our word muskeg. *Anmoorig Wald* is a special term that was used for the forests in the region of *Aapamoor* (*Aapasuo*), "a thin forest on partly peaty and partly mineral substrate" (Auer, 1920), probably corresponding to what we would call dry muskeg or park-like Black Spruce. "Muskeg" in technical use (Radforth, 1952), although not in common use, best corresponds to the European term, peat lands (Tansley, 1939). Of course, the important line of differentiation is that the European forest does not contain Black Spruce which is the single plant species that characterizes the present forest and separates it from other vegetation types such as wet tundra, or high brush bog types.

Analysis of Vegetation Patterns of the Bog Surfaces

On the bogs are orderly patterns of patches and ridges of more mesophytic vegetation superimposed on a general meadow-like

cover of sedges and low heaths growing in sphagnum. The regular patterns take two forms: 1) the clumps of Black Spruce almost as regularly spaced and ordered as trees in an orchard (Figures 14 and 21), 2) the bog ridges, often lined with Black Spruce trees, which occur as festoons or nets. These bog ridges are the strings of the *Strangmoor* of European authors (Figures 14, 15 and 18). The terms "*Streifensumpfe*", "*Streifensumpftaiga*", "*Polygonsumpfe*", and "*Polygonsumpftaiga*" have also been used for particular features similar to these.

The explanations of these vegetational phenomena are included in the effects of frost action broadly conceived. As Troll (1944, page 639) says in his review of frost action and structural soils:

> "When you pass south from the general continental tundra of north Europe into the region of needle-leaved forests, the frost forms on bog surfaces change similarly. As Auer has pointed out for Lapland, palsen [ice-centered peat hummocks, WHD] become lower and oriented into groups and at the same time they form transitions to peat waves that take on the net-like, sinuous patterned appearance of the bogs in southern Lapland. *Strangmoor*, however, are really only a special form of the more inclusive bog type called *Aapamoor* ..... If the bog surface is horizontal or only very slightly sloping, then the hummocks are more or less isodiametric and scattered throughout the marshy, grassy bog like little islands. On the other hand if the slope is greater, then the mounds become stretched out lengthwise into cords with their long axes perpendicular to the direction of slope like the solifluction ramparts....."

My observations at tree-line in Eastern and Central Canada and in Alaska agree with Troll's conclusion that *Strangmoor* are a phenomenon of the region just south of continuous permafrost. At least their distribution coincides with the northern edge of the boreal forest, which, within 200 mile limits, corresponds with the limit of continuous permafrost. The vegetation patterns of the Upper Kuskokwim River Region can probably be explained in the terms Troll suggests.

MEANING OF THE PRESENCE OF SPHAGNUM

That the growth of the bogs and of sphagnum is ultimately dependent upon conditions of climate in the broad sense is clearly indicated by the fact that *Sphagnum* is less abundant in species and individuals in the tundra regions of Alaska and Canada than it is in forested areas of these regions. The number of arctic *Sphagnum* species recorded by Steere in Polunin (1947, p. 377—382) is about half of the number known from the Kuskokwim

Valley. J. B. Tyrell (1910) used the absence of Sphagnum bogs in the tundra in the regions east of Athabaska and Great Slave Lakes as evidence that forests had never grown there, since these bogs according to him are limited to the forested regions. Middendorf (1864, p. 737) pointed out that Sphagnum is noticeably less common on the tundra of Siberia than in the forested regions, and as he says, it is not "at home" there; "climate relations in the far north are not suitable for peat formation". In the Upper Kuskokwim River Region, however, Sphagnum moss carpets about 75% of the land surface not including the bogs. "The peat derived from the heavy growth of Sphagnum mosses over all the swampy lands may be considered the most characteristic and widespread of recent deposits" as Maddren (1910, p. 61) says in referring to this region.

My observations from the air near Fort Churchill, Manitoba, north of Fort Chimo on the Ungava Peninsula of Quebec, and in Alaska all indicate that *Strangmoor* are a phenomenon very closely associated with tree line. Where I have seen them they extend only a very short distance onto the tundra beyond tree line, and they extend perhaps only 200 miles south into the forest. The distribution that Troll (1944) reports from northern Europe and Asia agrees with this. The reason is probably that the conditions suitable for the luxuriant growth of sphagnum occur in that area and, as will be discussed later, that the same conditions produce characteristic patterns of frost activity responsible for the ridge pattern.

The relative scarcity of Sphagnum mosses in the "flats" of the Yukon and Tanana rivers requires some explanation if these statements are correct. One reason is correlated with the fact that, as Katz (1926) and others have pointed out, fire destroys the identity of a peat bog. A marsh of sedges and grasses (a fen in British and Scandinavian literature) usually takes its place. W. S. Benninghoff has frequently told me of the conspicuous evidence of repeated fires in the flats in the Yukon Flats area and has remarked on the almost complete absence of evidence of fire in the Kuskokwim River Region.

In the few areas of the bogs in the Upper Kuskokwim River Region that have been burned, there is a conspicuous increase of grasses and sedges and decrease of sphagnum.

A second reason is concerned with the percolation of soil water.

In the Scandinavian classification of bogs (von Post, 1937; Sjörs, 1948), those bogs which derive their moisture from water percolating through the soil (soligenous mires) are characterized by marked decrease of *Sphagnum* and increase of grasses and sedges. Fully developed peat bogs, according to the Scandinavians, depend largely on water falling as rain (ombrogenous mires) and not that derived from the water table because of topography (topogenous mires) or movement through the soil (soligenous mires). It is my understanding from W. S. Benninghoff and J. R. Williams, who have studied that area over several years, that the sediments of the still-braided rivers, Yukon and Tanana, in the region where the flats are found, are coarser than those of the Upper Kuskokwim. Perhaps a combination of both the coarser sediments allowing more water percolation and the widespread occurrence of fire has prevented the full development of peat bogs and has contributed to transformation of them into fens over wide areas where peat bogs may have occurred in the past.

STRANGMOOR

The most conspicuous vegetation pattern is that of the serpent-like moss ridges. These are evidently a response to down-slope forces. Their vegetation has already been described in detail.

Auer (1920) has presented an exhaustive study of *Strangmoor* in Finland, and nearly all the references to theories of origin are taken from his publication. Troll (1944) refers to it as the most satisfactory and up-to-date explanation of bog ridge formation. I have translated his summary of Auer's discussion of the various theories on ridge development as follows:

"V. Auer (1920) has presented a precise investigation into the nature of *Strangmoor* and their meaning in earth climates, that brings together all earlier-presented theories. *Strangmoor* express climatic conditions of frozen ground on a gently sloping bog surface in boreal climate (needle-leaved forest). To mention briefly, Fellman (publ. 1906) and Norrlin (1873) find bog ridges (*Strangr*) similar to *Palsen*. Hjelt and Hult (1885) recognized that they are linked to sloping bog surfaces. The essential process of the genesis was seen by G. Anderson and Hesselman (1907) in the slow flow of the peat, especially in spring through the strong action of meltwater over the still frozen substrate. The formation of bog ridges is accomplished 'wholly analogous to the formation of solifluction terraces in arctic regions' that had already been interpreted at that time. Tanttu (1915) further recognized the meaning of the differentiated ground ice structure.

"During the process of freezing in autumn, ice first appears in the bog

hollows (*Flarken*), then later in the ridges due to the poorer heat conductivity of the dry hummock peat. Thereby, at one time, a squeezing of the peat occurs in the ridge, entirely similar to the case in *Palsen*. In mid-winter, on the other hand, the ridges freeze more solidly, as they have a thinner snow cover and are readily blown clean, which produces a further vaulting effect. In spring the ice persists in the ridges much longer than in the hollows, and within the ridge longer in the outer and lower, indented, steep flanks. These lie beneath the effects of the snow melt-water which has pushed some ridges outward. Autumn formation of ice in the hollow on the other hand begins in the wettest part that has been warped outward. According to Auer, the process in spring, the overflow of meltwater, and the uneven thawing of the winter ground ice are of critical importance. The hypothesis for *Strangmoor* is a strong expression of winter ground frost and summer thaw. They are a true frozen ground pattern, but without permafrost in contradistinction to *Palsen*."

This explanation is presented from a geologist's point of view. Troll has not considered that in these features there are living plants of different growth rates. He has considered the hummocks and ridges as physical features and has omitted L. von Post's suggestion that differential growth (hydrophytism and mesophytism) in wet or dry places, referred to by Auer, is a genetic factor in the formation of these micro-relief features. H. Ranken (referred to in Auer, 1920) suggested that the plant growth expands laterally from hummocks, and emphasized that knowledge of the formation of the patterns must involve knowledge of the underlying peat structure, i.e. the history of formation of the irregularity. Troll's emphasis is upon the subsequent development of ridges by frost action exaggerating the differences initially established. Neither he nor anyone else has presented an adequate explanation of the initial establishment of the bog ridge and the intervening bog hollow.

Troll says that winter freezing in the hummocks causes additional doming although ice does not persist over the summer. This is hard to consider of more than temporary effect from the point of view of plant growth, as the doming occurs during the period of plant dormancy. Troll does not consider the details of Auer's theory, and so refers only briefly to the critical feature of persistence of bands of ice leading to the lateral growth of hummocks.

Auer's 1920 paper remains the best discussion of the development of this geobotanical feature. Although he does not adequately explain the initiation of the pattern, he discusses the existing theories, their merits and disadvantages and contributes his own

discoveries, amalgamating the whole into a paper which should be recognized as a classical contribution to the study of ecology. I have translated his review of the existing theories at the time of his writing as follows:

"I) They are the normal result of a struggle between those processes a) constructive and building up the bogs [including *Scirpus cespitosus* in Finland, WHD], and b) those of regressive nature making hollows.

"II) The bog is raising itself above the water level, and bog ridges develop by formation of extensions of hummocks. Both bog hollow and bog ridge represent results of progressive processes, and the topography of the basin occupied by the bog has an especial influence over the pattern of ridge and hollow.

"III) The features depend in part on slipping of the peat. When peat is soaked it slips slowly and stops when the ramparts reach a certain height."

[This is the most readily concluded explanation and many still subscribe to it although no one has presented adequate evidence of any movement to support it.]

"IV) Bog ridges are the remains of a *Sphagnum fuscum* Wiesmoor (sedge meadow) which has been torn by expansion and the holes are occupied by bog hollows. The advance or growth of bog hollows is due to climatic or orographic forces.

"V) The Sohju theory — that plant remains and slush in early spring are gathered into lines (windrows) and freeze irregularly; the snow meltwater exaggerates these."

[This theory would explain the pattern of ridges in relation to slope and islands, and depend on the other theories for their spread and development. It has the disadvantage that at the time Auer published no one had been able to find windrows of size sufficient to offer an adequate start for the ridge. I believe, however, that my observations on Bylot Island, Canadian Northwest Territories, in 1954 indicate that this is very close to the actual mechanism for the establishment of the pattern. These observations are discussed later.]

"VI) Hollows develop by, a) freezing irregularly of rifts in the bog made by running water, at the autumn freeze-up, b) freezing in the breaks caused by breaking through and upwelling of water from under the ice."

In his paper Auer (1) establishes the critical importance of relative wetness and dryness in ridge development, (2) emphasizes that the kernels of spread are sphagnum tussocks, (3) nowhere emphasizes that ridges are a simple superposition of less hydrophytic species of sphagnum on more hydrophytic, although his illustrations point it out, (4) concludes that neither hollow nor ridge can exist without the other, and (5) believes that flooding

and drying are indirect in their effect on the extension and interconnection of hummocks.

There are many processes and forces involved in the development of ridge patterns according to Auer. Six processes are emphasized by him.

"1) In the north, spring thaw is rapid and gives meltwater great force. The layer above the frozen ground is thin, and becomes lifted and may be broken and slip. The products of this high water and snow debris collect in lines.

"2) He records isolated data on actual ridge movement with *Scirpus caespitosus* tussocks, and suggests that the distortion of ridges is strongest of all during fall flood before the ridges are frozen in. In spring ridges are still anchored so that they are compressed and elevated by the pressures rather than being moved."

[There seems to be no evidence of any extensive fall floods in the Alaskan bogs. Observations indicate, on the contrary, that there is a progressive drying from July to October.]

"3) Cases in which ridges result from the actual overthrust of peat due to movement of the whole bog seem to be restricted to the borders of large lakes. He found only one case of *in situ* slipping.

"4) The size, number and spacing of bog ridges does not seem to reflect the angle of slope. On nearly level bogs, there is correlation of the topography of the bottom of the bog basin with ridges, but this does not seem to hold if there is any slope.

"5) Winter freezing pushes against the bog ridges from the bog hollow; persistent frost in he ridges protects them from spring floods.

"6) In spring, water percolating across the bog is warmest after passing over a hollow and coldest just after emerging from a frozen ridge. In fall the water is coldest after crossing the hollow. Therefore ice forms near the ridge and squeezes it."

Auer establishes, as field observations indicate, that because there is no surface displacement of peat strata, there is no horizontal movement of peat. However, his chief contribution is that he was able to demonstrate that in bogs at high latitudes the last remnants of ground ice persist under a hummock in strips elongate at right angles to the direction of slope, forming a peninsula to the sides of a hummock. Strips of ice similar to these can be found in spring in temperate regions when the ice melts from ponds or especially shallow pools in swampy places. They are of short duration and soon blow to the shore.

Auer goes on to say that drifting slush and snow debris, torn up plant remains, and silt borne on spring floods will collect against areas raised by the persistence of ground ice. These will be elongate across the slope. Such debris contributes to the dryness

locally by formation of a tide-line-like collection, and encourages colonization by less hydrophytic mosses. Any slight advantage is important in the short, intensive growing season. It can be shown that thawing of ground ice is very dependent upon sphagnum cover and the relative protection of the different species, as Tanttu pointed out (1915). The less hydrophytic species are the better insulating agents. These will tend to encourage further persistence of ground ice, further colonization by the less hydrophytic sphagnum and extension of the hummock into a ridge.

Once started, such a process will accelerate by its own effects. The initial elevation allows the formation of hummocks which grow by lateral extension. Hummocks coalesce and act as further dams for slush and floating debris. At this stage the element of frost-push from winter ice in the hollows enters, narrowing and elevating the ridge and preventing its expansion downslope. Because in the autumn the water is coldest after crossing a hollow, ice forms downslope first and then water movement pushes to the sides. Mid-winter ice-push thrusts hardest along the long axis. These forces tend to elongate hollows across the slope too. Auer allows that freezing in the hummocks is important at a late stage, but disagrees with Helaakoski and Tanttu who considered it of fundamental significance in the initial establishment of the pattern.

In my excavations ridges are formed by the simple superposition of one sphagnum species upon another, *Sphagnum balticum* or *S. recurvum* growing on *S. Dusenii; S. papillosum* growing upon *S. Dusenii, S. balticum* or *S. recurvum; S. fuscum* growing on any of the preceding, usually *S. papillosum* or *S. balticum*[16].

16) Tansley (1939) shows (after Osvald, 1923) the same three stages of sphagnum sequence from wet pools to hummocks occur in Europe that occur in Alaska. In Britain *S. cuspidatum* is followed by *S. papillosum* which is overgrown by *S. rubellum*. *Sphagnum cuspidatum* is a more southern representative of the *Cuspidatae* group of Sphagna (*S. Lindbergii, S. Dusenii, S. balticum, S. recurvum*), to which the sphagna of wet areas in Alaska belong. Sjörs (1948) comments that *Sphagnum Dusenii* and *S. Lindbergii* belong to more northern bog types than those Scandinavian bogs he studied. *Sphagnum papillosum* seems to occupy the same position in the vegetation of the bogs of Scandinavia and Alaska but *S. fuscum* in Alaska fills the sites on the tops of the hummocks more often than *S. rubellum* which occupies that site in Great Britain. *S. rubellum* in Alaska forms a deep carpet on damp, very gentle slopes rather than being widespread on hummocks in bogs. As Tansley points out, *S. fuscum* is more common outside Britain than *S. rubellum*, and is more important in hummock formation in Scandinavia than *S. rubellum*.

As a specific example, a vertical section was dug across the right-hand ridge at the top of the lower diagram Figure 19. The sides of the ridges are steep on the sides away from the lake, and gentle on the side toward the lake.

The section showed

1) *Sphagnum fuscum* and its dead bases to a depth of 10 inches;
2) a 7 inch layer of compacted *Sphagnum papillosum;*
3) a 15 inch layer of compacted *Sphagnum balticum.*

The water table was at a depth of 15 inches, near the base of the *Sphagnum papillosum* layer. Tussocks of *Eriophorum vaginatum* were rooted at 10 inches, right at the top of the *Sphagnum papillosum* layer, which seems to be the rule for these tussocks.

There is no indication of slipping or horizontal movement of peat or surface displacement of strata, although bog ridges are consistently higher and steeper on their downslope margin than on their upslope edge. The horizontal bedding of the peat layers precludes any formation by frost heaving such as Sigafoos (1951) has suggested for peat ridges on Seward Peninsula, Alaska.

Wenner (1947), however, who seems to be the only person who has dug a cross-section through a ridge to the bottom of the bog, reports that the ridge and hollow retain their separate identities all the way to the bottom without the alternation of hummock and hollow positions and functions that Osvald (1923) regards as fundamental to bog growth, and without superposition of the progressively more mesophytic species of sphagnum just discussed. As Osvald described it, in wet places at the base of a hummock grows *S. cuspidatum* which is replaced by *S. papillosum. S. papillosum* is overgrown by *S. rubellum* or *S. fuscum.* The hollow between hummocks so formed is occupied by *Sphagnum cuspidatum.* In time, another hummock forms in what was the hollow, overtopping the first hummock. In this way an area is first hollow, then hummock, and its position alternates as the surface of the bog is raised by growth of peat. Such a process in action in the *Strangmoor* would suggest that ridges would become overtopped by growth of hummocks in the neighboring hollow. No excavations were made specifically to test such an idea, but those excavations that were made gave no indication of the possibility of its action.

To return from a discussion of the literature on the subject to the process of formation, bog ridges are developed on the surface

of a more or less swampy bog as the surface gradually becomes drier. As the bog water-table is lowered the uneven bog surface allows colonization of mesophytic mosses first on those localities that are slightly raised above the water-table. Hummocks appear and, in some cases involving *Scirpus cespitosus*, it has been suggested that these are bodily rearranged during spring floods. The evident expression of the hummock development is long lines of bog ridges at right angles to the slope. Collection of water where drainage is impeded by these bog ridges has been said to swamp the surface growth and thus form bog hollows.

Auer's explanations are very complete, but they do not adequately explain the initial establishment of the pattern and the fact that bog ridges resemble waves or ripple marks in form (Figures 14 and 15). They bend upslope near islands of forest and belly downslope in the open slopes between such relatively more consolidated places. In this they resemble the pattern of waves that are slowed up at the margins of a stream and are carried farther down where the water flows fastest in the center. Auer's explanation does not account for the ridge 100 yards long and 3 yards wide. That such a ridge is formed by the aggregation and lateral expansion of hummocks seems to ask too much of coincidence. Ridges should fork and form clumps if there were not initial and additional forces.

In other words, the first establishment of the pattern of bog ridges or *Strangs* is still not explained. Two alternative hypotheses are offered for this. First, in a pliable medium such as a sedge meadow carpet in loose-growing sphagna, downslope sagging of the entire sodden surface will occur. I have seen waves formed by such sagging in the channel of a small stream choked with sphagnum. This sagging need not produce any convolutions or distortions of strata of peat. Movement is slight at best, as is shown by the minor surface expression, but has been observed to produce waves of slight elevation which were sufficient to allow the top to dry out. On these, less hydrophytic sphagna can colonize. This movement is probably not of sufficient magnitude to create the bog ridges by itself and it seems to occur only when the whole sedge carpet is completely thawed. It may or may not be of importance in the initiation of the bog ridge pattern, and clearly is not of the importance of the second mechanism suggested.

FIGURE 21. CLUMPS OF BLACK SPRUCE. This is a photograph of a forest of Black Spruce near the Alaska border in the Yukon Territory. The clumps of taller trees are spaced in a pattern similar to that shown in Figure 17. The regularity of the clumps is especially conspicuous in vertical aerial photographs.

FIGURE 22. THE CONTINUING PROCESS OF THAWING AND RECOLONIZATION. This low-altitude photograph, taken in the Upper Kuskokwim River Region, shows bogs actively thawing into the alluvium and undermining forests. The margins of such bogs have a coarse sedge meadow or open water zone next to a high, steep bank. At the same time, sedge meadows are consolidating a carpet in the shallow standing water in the center of the photograph.

FIGURE 23. RIFFLE FORMATION BY MELTWATER FLOOD ON BYLOT ISLAND. Meltwater flowing as a sheet across frozen ground appears in terracettes with a riffle at each riser. The distribution of frost table is discussed in the text. The festoon pattern of the riffles closely resembles the pattern of bog ridges in Aapa bogs.

FIGURE 24. PEAT RIDGES, PONDED MELTWATER AND A MELTWATER STREAM ON BYLOT ISLAND. Meltwater has been ponded by the large peat ridges extending away in the photograph. A temporary meltwater stream runs from left to right in the immediate foreground. Festoons of minor peat ridges resembling those in Figure 23, can be seen running across it. These ridges occur on the gentle slope from one raised beach level at 35 feet to another raised beach at 16 feet above present high tide. The ice axe in the middle distance supplies scale.

Second, where torrents of water (from sudden thawing of snow or a downpour of rain) run in a sheet in less consolidated materials over a hard surface, riffles are formed and after the water has subsided debris collects on the festoon-like ridges created. This suggestion seems to return to the Sohju theory discarded by Auer, but it actually does not involve the collection of debris and refreezing of it that that theory requires. The pattern of festoons has been seen on the floor of a pine forest after an 11 inch rainfall, and in this case was expressed by step-like ridges of pine needles alternating with levels of the black organic soil below. Most extensively and clearly, however, the pattern has been seen where snow meltwater ran over frozen ground, as was the case in June 1954 on Bylot Island in the Canadian Arctic Islands. The features resulting from these soil processes were studied in detail on Bylot Island to investigate whether the phenomenon observed there might have some application to the initial establishment of bog ridges.

Figures 23 and 24 show that a sheet of water flowing across a surface of frozen ground creates steps and falls, whose steep places occur in festoon patterns. The same effect is well-developed in the beds of small streams in the same area and may be related in origin to the falls and levels of the valleys formed by valley glaciers as described by Matthes (1930). Figure 24 shows, in the foreground, crescentic riffles on which moss and sedges have grown and formed ridges. In the background similar ridges are large enough to dam a body of meltwater and are closely similar to bog ridges and bog hollows [17]. In each pond held up by a peat ridge, the level of the water decreases stepwise downslope the way it does in terraced rice-paddies. In at least three ponds held in by large peat ridges, the pond below the ridge was 8 inches lower than that above. One of these cases is shown in Figure 24.

17) The formation of the larger ridges in this particular case, however, is considerably complicated and modified by the appearance in unconsolidated deposits of large cracks resulting from the cracking of perennially frozen ground. The cracking of the frozen ground is occurring at present at all elevations and is the result of the strains of isostatic readjustment correlated with the retreat of the ice sheet locally. The cracks started in this way are secondarily modified by frost-thrusting which raises a ridge on each side of such a crack. In wet places mosses and sedges grow more luxuriantly on these ridges, producing a pattern of pairs of peat ridges at times as regular and straight as if man-made. These readjustment cracks and peat ridges will be the subject of another paper.

In nearly all discussions of the formation of ridges and hummocks I have found, the chief emphasis has been on the persistance of a ridge or kernel of ice. To test this, the depth to frost below the surface of the soil and below the surface of the water was measured by probing from riffle to riffle across 40 such levels. Depth to frozen ground was tested daily during the period June 20—July 4, including that of violent thaw, June 24—29, 1954, and was found to be essentially regular. Below each step or steep part of the riffle, the frost was much closer to the surface (1—1 ½ inches on June 28); crossing the pool toward the next riffle the depth increased regularly until it reached maximum on the upper edge of the next riffle (2 inches below the surface of the soil on June 28). The surface of frozen soil was concave upward from the upper edge of the pond to the lower and resembled the impression made by pressing a clam shell into wet sand. The depth to the frost table was similar to that of the water; where the water was deepest, the depth to frozen ground was greatest below the surface of the soil. The close correlation was that where melt water was deepest, the depth to thaw was greatest, and where the water was shallowest and moved fastest the depth to frozen ground was least. The contrast in depth to frost from above the riffle to below the riffle was as much as 1 inch in a distance of 8 inches, and this combined with the pilling of mosses and sedges by the water current to act as a dam. Auer noticed similar phenomena in *Strangmoor.* He reported that the water is coldest just after emerging from a bog ridge and warmest just before flowing into the next one downslope.

In the arctic deposits studied, once a peat ridge was formed the ridge was often wall-like, both upslope and downslope, but repeated tests indicated that the thaw advanced equally rapidly from the surface into the soil in all places. The depth to frozen ground was as great or greater under a ridge as under a hollow. Because of the greater depth of vegetation and turf in a ridge, there was a noticeable rise in the frost table, although at any point in the ridge the frost was usually farther below the turf surface than in the low places between ridges. In such places the frost acted as a real dam holding back the flow of water as Figure 24 shows. But the ice did not persist as a kernel in the hummocks,

and in the riffles the ice persisted just below the step rather than under the terracette bank itself.

The total effect of the formation of riffles by differential thawing during melt-water flow across the surface was the creation of hollows where the water collected and ridges (riffles) which dried out relatively early. In plan the riffles extended farthest downstream where the current was strongest and as a result a fan shaped terrace was produced across the stream which closely resembles the festoon type of peat ridge in Alaskan bogs. The terracettes on Bylot Island were seen to vary from 1 to 4 yards across and from 4 to 35 yards long.

In addition to the long, festoon ridges, short isolated hummocks or ridges 5—75 feet long were found, again running across the slope. Where correlations were made these coincided with places where microtopography concentrated the flow of melt water while snow still lay in banks over most of the ground. These forms are transitional between *Palsen* or ice-centered hummocks and *Strangs* or bog ridges, and show that the essentials of their formation as described by Troll (1944) are correct although some of the details of their initiation are probably different.

The feature of main importance to the formation of bog ridges in subarctic regions is that water flowing across frozen ground forms riffles which appear in the form of festoons. The result is a series of steplike levels. At the margin of each level, later development of moss and sedge turf forms a ridge. Standing water in the ponded areas thaws deeper into the frozen ground during the thaw and exaggerates the ridge and hollow pattern started in the riffles. Similarly when melt-water flows across the Aapa bogs in spring, it flows across a frozen substrate and creates conditions similar to those responsible for the riffles and festoons on Bylot Island. The formation of the riffles not only produces the drier ridge, but also the ponded water in the bog hollow at the same time. All students have agreed that the bog hollows and ridges cannot exist one without the other. This is the first hypothesis which accounts for the origin of the two at the same time and subsequent growth together in a way would find support in Wenner's excavations in Labrador. The establishment of the pattern is a physical phenomenon resulting from the flood of water through or over loosely compacted, thawed vegetation resting on a frozen substrate. No lateral movement of vegetation or turf is involved but rather only

the differential effects of erosion and thawing by a meltwater torrent.

There is further evidence that patterns of ridges are a response to physical forces not explained here and, in fact, not understood. Patterns which seem to be identical to the nets of *Strangmoor* have been seen on the surface of brash ice collecting on a slope within range of salt spray (Figure 17). In the case observed, water seeped up through a hole in the ice, thawing the ice already present and freezing itself while it ran across the surface. The alternative that a skim of ice had first formed and later collapsed as the water under it escaped was investigated. Our field studies indicated some breaking and sinking of the ice, but much more conspicuously modification by formation of ice over the ridge without fracturing. This indicates at least that physical forces independent of the vegetation are able to create the pattern, and indeed as suggested before, that the vegetation only capitalizes on and emphasizes microtopographic features which frost action has created.

If we make the assumption that formation of riffles as meltwater flows over the frozen bog can actually form ridges of sufficient size to initiate a pattern of bog ridges on a large bog, we would have an adequate explanation for their form and structure. Such an explanation would also account for the increase of ridges and their closeness together at the margins and downslope ends of sloping bogs in contrast to their wider spacing in the middle. This sort of distribution is found in both raised bogs (*Hochmoor*) and regional bogs (*Aapamoor*) (illustrations in this paper and in Troll, 1944). Such a system would explain the transverse small-scale pattern or ridges within the larger pattern. Most important, it would not contradict but would be a source of initiation of the pattern subsequently acted on by the forces so completely handled by Auer.

On the raised bog ridges formed in this way, more mesophytic sphagna can colonize and their growth will allow differential persistence of ice. Persistence of ice under hummocks as Auer described it will maintain the segment raised in this way while the rest is flooded by water as it thaws. The remnants of frozen hummocks are elongate across the slope and will collect the slush and flotsam of spring high waters. Spring floods erode and push the hummocks which develop on such relatively firmer substrates,

ordering them further into lines across slope. Persistence of ice in the hummocks protects them from further movement while they are modified in outline by ice-push which elevates and elongates the bog ridges and lengthens the basin of the bog hollow. Dam action of these bog ridges leads to collection of water in the areas between, swamping the vegetation there and exaggerating the differences between bog ridges and bog hollows.

The patterns are phenomena of the general process of frost action, but no completely adequate explanation of their development and especially first establishment is yet available. Observations during the spring thaw in Alaskan or Scandinavian Aapa bogs can easily establish whether the forces suggested here are actually effective. If such is indicated, then detailed marking and mapping of changes in ridges can indicate whether changes are still going on, where they occur, and whether new ridges are forming on parts of the bog.

REGULARLY DISTRIBUTED ISLANDS

A second remarkable pattern on the surfaces of the bogs is that of clumps of trees regularly spaced as if planted (Figures 14 and 21). It is poorly expressed in the Upper Kuskokwim River Region but clearly expressed in the Cook Inlet area and along the Alaska Highway near the Yukon border. The clumps of trees may be isolated in a generally treeless bog (Figure 14) or be clumps of taller and healthier trees in a generally poor and thin bog forest (Figure 21). Often there are dead trees in the middle of the clumps. Sometimes such trees are split from the base, and in several cases tears and other disturbances of the moss carpet have been seen. The islands are slightly elevated above the general surface of the bog. Frozen ground has been found as late as August and September underneath them. The clumps are considered to be expressions of factors operating in the climatic transition zone between ice-centered hummocks (*Pounu* — Auer, 1920; *Baidsaraki* — Pleske, 1928; *Pingo* — Porsild, 1938; *Thufur* and *Palsen* — Troll, 1944) and the sinuous moss ridges (*Strangs*).

A partial explanation is as follows. When the surface of the quaking bogs has become well vegetated with sphagnum, sedges and brush, ice hummocks develop as Troll (1944, p. 633) indicates. Local persistence of frost elevates the moss, dries it, and allows more aggressive growth or colonization by other species. The

plants act as a protecting insulation and the ice kernel grows, further elevating the hummock. Within the regions of forests such elevations would offer better drainage, aeration, deeper root penetration and more stable substrate for seedbeds for trees. Their position on the elevations favors these trees over those immediately around them allowing them to grow fast and tall. Subsequent frost action and heaving centered around the ice kernel have killed and split some of the trees and torn the moss carpet, but the layering of Black Spruce has maintained a clump, marking the site of the elevation.

The ability of lower branches to produce roots when covered with humus, layering, is widespread among the conifers, and these sprouts will live on when the main stem has died. This ability, however, is conspicuously better developed in Black Spruce than in the other conifers of Interior Alaska. For this reason the development of sprout clumps is a phenomenon peculiar to Black Spruce forests in this area.

I have seen frost-heaved mounds regularly but widely spaced on nearly flat muskeg surfaces along the Alaska Highway (near the Alaska-Canada border and northwest of Big Delta, Alaska), where the vegetation mat has been removed beside the road. These appeared very similar to the *Baidsaraki* illustrated in Pleske (1928), but were much more widely spaced. The regularity must reflect factors similar to those that create the regular sizes of tundra polygons (both those due to ice-wedges and those not), and suggests that in saturated silt-organic soil there are regular limits to the spacing of hummocks. Perhaps structural readjustment of the whole lowland area due to movement resulting from removal of the ice sheets is responsible.

It is obvious that many other forces are concerned with formation of polygons and frost crack patterns and that forces not included in what has been suggested must be involved. A feature entirely unexplained is that the initial colonization of emergent sphagnum in open water is often in clumps of quite regular distribution (Figures 14 and 15). How these form and why they show a regularity of pattern is not understood, but when the whole wet area is overgrown, the initial colonies will have had the opportunity to become more compacted. The compacted sites will be suitable for the initial colonization of trees, and this in its turn will lead to the patterns described.

DISCUSSION

Geological Implications

There are several geological implications of the processes modifying the surface of the floodplain. First, bogs are a serious impediment to human occupation; second, they are a source of confusion of stratigraphic sequences; third, they are a potential source of the mucks; and fourth, they are an instance of soil instability which has limited or eliminated forests.

1) EFFECT ON MAN'S USE OF THE LOWLANDS

Large areas of the alluvial lowlands of the subarctic regions of Alaska are covered with peat bogs. These alluvial lowlands are the most accessible and potentially fertile lands of the region, but bogs have engulfed large sections of them. Such places are entirely unsuitable for settlement. The bogs are so unstable that they are a serious obstacle to travel. Even in winter, when loosely compacted vegetation and peat occupying the sodden bogs will freeze only to shallow depths because of poor heat conduction, peat near to the surface may remain unfrozen locally and tractor trains crossing such bog areas have been lost by breaking through the ice and sinking into the mire below. Drainage undertaken on a large scale would be required to make bog areas useable, and it is not proven that drainage would be effective under the present climatic conditions.

2) EFFECT ON STRATIGRAPHIC SEQUENCES

At the advancing margin of a peat bog, where thawing of the banks undermines a forested surface, as much as 10 feet of sediment may be considerably altered by slumping. Also, water percolating through the soligenous bogs can carry silt and pollen grains into the subsurface levels. Such activities, although at any one period they do not penetrate to great depths, can contort, reverse and complicate stratigraphic sequences by secondary deposition both in the bog and in the deposit that is being engulfed. They exist as a source of confusion and error in pollen and stratigraphic sequences in any bog which has been subject to the conditions of perennially frozen ground outlined in this paper. Such distortions, because the stirring is limited to certain levels,

will still allow misleadingly reasonable vegetational sequences. As is the case with many other sources of error in the study of pollen analysis, this is not so serious as to invalidate results from carefully studied bogs, but must be considered as a real danger in bogs which may have had water flowing through them while they were growing. It is probably not of real danger, however, in either a pot-hole bog (a type of topogenous bog) or a raised bog (*Hochmoor* or ombrogenous type).

3) THE PRODUCTION OF MUCK

The incorporation of a large amount of silt of either alluvial or aeolian origin with finely divided organic material either by repeated bog cycles or deposition by percolating water produces a deposit which fits the general definition of muck (Eardley, 1937). Similar mucks are accumulating at present. Although most of the valley mucks of the interior of Alaska are depositional slope or alluvial deposits, the present phenomenon will explain the existence of mucks in valley centers away from slope movement.

4) ELIMINATION OF FORESTS BY SOIL PROCESSES

As the cycles of bogs and forests are conceived here, frost-produced soil conditions are responsible for the elimination of the forests. Some authors (Denny, 1940) have indicated that forest vegetation is the limiting factor in the distribution of frost-produced patterns in the ground, and other authors that structured soils are evidence of treeless conditions. But Benninghoff (1953) has shown that in southern Alaska remarkable frost features are being produced in the soil today under a forest cover. It may be that, at the southern limit of patterned ground and other expressions of frost action, strongly rooted vegetation can control the expression of frost-movement patterns. In such a case it is an academic question as to whether climate or vegetation is responsible. For it is obvious that where frost action is less effective the influence of vegetation is more effective. In the Upper Kuskokwim River Region evidence shows that trees have been uprooted by frost action, that on north slopes where frost activity is widespread trees are scattered, dwarfed and twisted.. Where such slopes are sheltered by rock outcrops, or where slopes are steep enough to allow efficient drainage the trees are healthy.

All these observations indicate that solifluction phenomena control the distribution of trees on slopes, and that the activity of bogs as a cryoplanation process is another phenomenon in which the physical activity of frost controls the distribution of trees.

Botanical Implications

There are several botanical implications from these studies which apply to the study of Pleistocene climates and vegetation. First, conditions for plant growth in Interior Alaska at present support the suggestion that the Interior was an area of plant persistence. Second, the conditions of climate, vegetation, frozen ground, and the distribution of forests and glaciers allow speculations on the periglacial climates of the northeastern United States: that mixed coniferous and deciduous forests survived close to the ice in a wetter but not markedly colder climate and that widespread permafrost and tundra are not indicated. Third, the vegetation of the bogs studied cannot be understood as a series of integrated entities or associations with interspecific dependencies. The Climax as a concept is found to be useless and confusing in contrast to Gleason's attitude that vegetation must be studied on the basis of the actions of individual plants and species.

1) Areas of Persistence During the Pleistocene Ice Advances

Large areas of forested lowlands exist in a region of cold, wet climate and soil instability in the Upper Kuskokwim River Region. This is supporting evidence for the conclusions drawn from floristic studies that there were large areas of forests in the interior of Alaska during some or several of the ice advances of the Pleistocene. The climatic conditions suggested for glacial climates of the Continental Ice Sheets by recent investigators (Willet 1954) are similar to those of Alaska today, and to the conditions Péwé has suggested to me for the formation of the Fairbanks mucks. Péwé suggests that the wind-blown silts were deposited on the hills during the colder periods and washed thence into the valleys and incorporated with organic material during warmer periods. It is necessary to have periods when vegetational cover was very limited for sweeping winds to stir up clouds of loess, and for formation of sand dunes, but a pool of forest vegetation must have been available close to these areas. The

indications of fossils for the conditions during the more or less continuous formation of mucks require that forests were not far distant. There is no justification offered in the present vegetation for suggestions that the forest was eliminated during the period of loess deposit and dune formation because climatic changes that would have a negligible effect on floodplain or hillside forests would bring about increase in the area of braided stream beds, and drying of the terrace surfaces.

On the other hand, D. M. Hopkins has told me that mucks on Seward Peninsula have accumulated in a wet climate and with a treeless vegetation similar to the present. In these various places, conditions during muck formation in the past do not seem to be fundamentally different from the conditions today in that particular area.

If the areas that are now in Black Spruce were wet and treeless during the ice advances, the well-drained sites on hillsides and river bottoms could still have sheltered forests which would have been sources for recolonization during warmer periods. The rapid appearance of forest vegetation after the retreat of the ice and the minor advances in speciation of trees and other forest species of plants and animals in interior Alaska argue strongly for the presence of isolated patches of vegetation like this.

Major climatic changes are not needed to explain the formation of mucks in valley centers as described in this paper. Bogs and bog activities are able to persist either in a period of loess deposit (when freeze-thaw cycles would probably play little part) or in mild periods (when thawing of the frozen lowland sediments would be widespread).

2) SPECULATIONS ON THE NATURE OF PERIGLACIAL VEGETATION IN THE EASTERN UNITED STATES

Evidence of periglacial climates

Frost-moved soils and rounded hilltops in the White Mountains, Adirondacks, Appalachians, and as far south as the Great Smoky Mountains clearly indicate intense frost action in those areas at some time in the past. In some of the central New England uplands similar forms are found, such as the solifluction lobes and stone streams at the Harvard Forest (Raup 1951, Stout 1952). Denny (1951) and Goodlett (1954) have studied similar forms in Pennsylvania.

A variety of evidence from the Mississippi Valley area seems to indicate intense frost climates there which tie in with essentially proven conclusions of frost climates in Central Europe during the ice advances. Adequate evidence (Davis, 1946; Frey, 1951; Potzger and Tharp, 1943, 1954) indicates the presence of spruce and fir in North Carolina, Florida and Texas, establishing the southward migration of elements of the boreal forest now extending south on the uplands into Virginia, North Carolina, and Tennessee.

The present studies in the Upper Kuskokwim River Region, however, indicate that it is dangerous to deduce from these evidences that frozen ground and a broad zone of tundra and south of these a broad zone of boreal forest stretched away from the ice front and that the climate was similar in those zones to the present climate of boreal forest and tundra regions (Deevey, 1949; Oosting and Billings, 1951).

The arguments in favor of a tundra zone and a boreal forest zone are of three types: first, fossil evidence of vegetation such as pollen of boreal trees in bogs in the southern United States; second, soil structures assumed to be developed in treeless areas with permafrost; and third, the assumption that the ice sheets must have been correlated with much colder climates which extended to the south of the ice. Each of these will be discussed in some detail.

First: assumed migrations of vegetation associations

It is assumed that if spruce and fir got to Florida they must have formed closed forests in the Virginia, Kentucky area, and there must have been a zone of tundra between those forests and the ice (Oosting and Billings, 1951). The idea of zones of tundra and boreal forests south of the ice grow out of the Darwinian concept of the major retreats of the vegetation zones before the advancing ice, abetted by the Clementsian concept of the "Climax Formation" which suggests the tundra formation advancing south. driving before it the boreal forest formation.

There is actually no evidence against a mingling of spruce, pine and deciduous trees in a mixed forest south of the ice, and Lucy Braun's work strongly supports such a condition (1947, 1951), although she does not give her data this interpretation. The evidence that does exist from pollen spectra describes a variety

of mixtures of trees with which we have little or no familiarity in the modern landscape, even taking into consideration the differential preservation of various types of pollen. This should not be surprising, however. We have to suggest climatic conditions during the ice age that differ from all those we know at present and unless we think of the vegetation as organismic, we should assume different combinations of plants would appear in response to different combinations of environmental conditions.

Hultén (1938) and Raup (1946, 1947) have shown that in the North, migration into the unglaciated regions has been at various rates and times from various sources. Individual species have migrated as individual plants rather than as a coordinated structured community. Yet that plants do migrate as associations is assumed in the suggestion that zones of vegetation retreated south before the advancing ice.

Furthermore, bird and plant subspecies indicate that minor advances in speciation, similar to those which took place in the isolated forests of interior Alaska, have taken place in the needle-leaved forest zone of the Appalachians. This requires isolation of the Appalachian populations and contradicts any suggestion that the boreal forests swamped the Appalachian ridges and lowlands during the Pleistocene.

Since the concentration and mingling of the forests during the glacial advances, the retreat of the ice has uncovered a great land surface allowing species to separate out according to their individualities and especially according to speeds of migration. The great vegetation zones of the North are perhaps best thought of as temporarily exaggerated in their segregation, as though in a great natural experiment resembling paper chromatography.

Second: assumed conditions for development of soil types and structures

In this second argument it must be clarified whether vegetation can be surely identified from fossil soils.

1) *Can steppe and tundra be told apart?*

Frenzel and Troll (1952) suggest both tundra and steppe vegetations, in contrast to forest, as suitable for loess deposition. This points to the possibility that the loess of the Mississippi drainage was deposited under grasslands. At the same time this

suggests the difficulty of differentiating by fossil deposits between prairie vegetation and tundra, for example, the tundra east of Great Slave Lake. Büdel (1949) uses the coincidence of 10.5° C. isotherm with tree-line and says that all colder than this is tundra and that other treeless vegetation is steppe. Over much of North America such an assumption is gratuitous; in fact, the use of any temperature or precipitation line beyond local coincidence is misleading as is shown, for example, in defining the position of the eastern edge of the grasslands in the mid-western states and the position of both the northern and southern border of the coniferous forest.

If tree-line can be drawn to separate steppe from tundra what does this mean? Few, including botanists, appreciate the variety of what is called tundra. Is it the tundra of western Alaska which approaches a peat bog in structure and aspect, or is it an area of lichens below low heaths and dwarf birch, or is it tussocks of sedges, or is it a grassy sedgy prairie, or is it mats of Dryas-Salix? These are all tundra, but they indicate very different climatic conditions.

We cannot define the climate of the tundra, nor can we define the climate of the grasslands; we cannot be sure we can tell the two types of vegetation apart. How then can we assume that ice age climatic changes (largely unknown) caused a specific type of retreat in the vegetation preserving the same associations that we find under present climates?

Furthermore, although it may be largely true, I am not convinced that the usual assumption that loess is deposited in treeless areas rather than forest is justified. I have seen a heavy mantle of wind-blown silt collecting in tall spruce forests near Kluane Lake in the Yukon Territory.

2) *Structured soils form under forests and a periglacial climate may produce only restricted tundra; do structured soils indicate regional tundra?*

Benninghoff (1952) has shown the development of spectacular frost features in south coastal regions of Alaska under tall forest vegetation. This does not contradict the use of soil structures as indication of frost climates, but denies the generally assumed requirement of permafrost and treeless vegetation. It throws doubt

onto assumptions that such soils indicate a tundra climate (J. Büdel, 1949; H. T. U. Smith, 1949 and many others).

The studies in this paper were made in lowland areas in a region where the uplands and many upper slopes are subjected to soil processes similar to those indicated in the uplands of New England and Pennsylvania. Tundra is found on the hilltops in the Upper Kuskokwim River Region and a mixed forest on the warm slopes and dry sites in the lowlands. This sort of vegetation distribution is much more reasonable, and better supported by the meager evidence available, than is a zone of tundra blanketing the uplands and lowlands south of the continental ice in New England. Goodlett's (1954) work in Potter County, Pennsylvania, has led him to suggest this same sort of distribution of vegetation close to the continental ice of the Wisconsin stage. He suggests unstable soils, structured soils, cryoplanation and down-slope movement of rubble on the uplands near (10 miles) to the Olean Moraines and presumes that the forests may have been eliminated due to soil movement responsible for the thick superficial deposits. But in the south of Potter County, at a distance from the Moraines measured in tens of miles, he and Denny find bedrock out-cropping through a thin mantle of debris and conspicuously less indication of the effects of frost climate. Goodlett suggests that stable areas of stream banks, floodplains and glacial outwash supported trees even near the moraine; and that a variety of trees occupied the southern part of Potter County. Furthermore, he suggests, as did Raup (1951), that the plants which persisted in such areas were those now living in the northeastern United States rather than those of the subarctic and arctic.

Stout (1952) in his studies of the soils in the Harvard Forest finds indications of frost movements, but the movements are of various forces and ages. Since the deposition of loam soils on top of the tills, the movement and congeliturbation have been restricted. This has preserved a sharp contact between the loams and underlying till which solifluction would have distorted and congeliturbation obscured. Evidently then, although the hillslopes show cryoplanation forms, these probably developed while the ice was in the vicinity and soils were relatively stable at a later time during the deposition of wind-blown soils presumably related to glacial advance.

Third: assumption that glacial periods are cold periods

Flint (1953) words this as follows: "The temperature minima (equivalent to glacial maxima of stratigraphic terminology) . . . ." This quotation represents the agreement of many geologists that the most important feature of the periods of ice advance is intensity of cold, although beyond the ice limits glacial periods are referred to as pluvial periods. Landsberg (1949) says "The only fact that can be stated without reservation regarding the relation between the Pleistocene Glaciations and atmospheric conditions is that during various stages of this epoch surface temperatures in many regions were considerably lower than they are at present".

There can be no doubt that there was cooling in the areas of the ice sheets, especially during the summers.

Bryan and Cady (1934) pointed out that the important change, however, is towards an increase of precipitation in middle and high latitudes and that the reason there are not continental ice sheets today is that there is too little precipitation in such places, especially during the cold months. In this vein Flint (1943), using ideas first published by Upham (1895) and Leverett (1916), suggests that the continental ice sheets started in the highland areas of Baffin Island, Labrador and Quebec, then expanded southwestward into moisture-laden winds. Precipitation collected where the winds were chilled at the margins of the piedmont glaciers. We are led to assume an increase in precipitation in the centers of expanse of the ice during an advance. It has further been established by radio-carbon dating that climatic changes during the Pleistocene were world-wide and synchronous (Flint and Deevey, 1951). It seems permissible, then, to suggest a climate at the margins of the continental ice sheets in which there was at least as much precipitation as there is in those regions today, unless the shift in storm tracks was so extreme that the ice fronts were in a rain shadow between two zones of increased precipitation.

There exist then the alternatives a) that the margins of the ice sheets were in a rain shadow between two zones of precipitation and b) that there was as much precipitation at the ice margins as at the ice centers and in the areas subjected to pluvial conditions south of the ice.

If we assume that the climates were cold and dry, we should have widespread development of wind-blown and structured soils

similar to those found in north-central Europe and central Siberia. Some of the greatest development of patterned ground, and structured and wind-blown soils occur in areas of strongly continental, cold and dry, climate (Troll, 1944; Muller, 1947). Well-formed frost features would be readily detected in such studies as Denny (1951) has made in Potter County, Pennsylvania. Frost features of considerable dimensions are found but they decrease precipitately in clarity and depth of effects from the ice border to the south.

Loess is found in the Mississippi River Valley indicating a dry climate, although not one proven to be intensely cold, as I pointed out before. In New England, although loess has been deposited, these deposits are thin and scattered. Perhaps there was little source for wind-blown silts in the broad hills and narrow valleys of New England. Similar valleys in Alaska are deeply mantled with loess. Perhaps all the loess blew out to sea before glacial anticyclonic northwest winds or perhaps the thin loess mantle can be used as an argument that there was a closed vegetation over much of New England in periglacial climates. Actually, then, there is no foundation in observable evidence to show that the ice fronts were in a rain shadow and that a continental tundra climate existed south of them. Instead, it seems justified to assume the other alternative, namely, that there was as much precipitation at the margins of the ice sheets as at the centers of nivation and in the areas subjected to pluvial conditions south of the ice borders.

If we assume a climate at the borders of the ice sheets cold enough to produce a zone of tundra and its associated permafrost with precipitation as great as or more than that of today, those areas are ideally situated for widespread formation of bogs, if not in the tundra zone, then in the forested regions bordering it. The species of sedges, heaths, and sphagnum involved in the formation of bogs in Alaska are all known at present to occur in the northeastern United States and in Eastern Canada north to tree-line, and there are broad alluvium-filled valleys available for the development of bogs. It does not seem justifiable to assume a broad zone of tundra without a zone of perennially frozen ground, and these without a climate on their southern border eminently suited to the formation of peat and muck. But in comparison to the deposits of peat and muck in Alaska today,

there are none. A possibility is that during the post-glacial climatic optimum, the peat and muck deposits disintegrated. If so, the action of disintegration was highly selective and avoided pot-hole and depression bogs in the same area.

Evidence is for a wet and cool but not cold climate

There seems to be little evidence to support an intensely cold climate, whether wet or dry, very far to the south of the ice. In addition, there is a body of evidence and thinking presented by astronomers and meteorologists interested in these same climatic changes which indicates dampness without intense cold. Bell (1953) and Willett (1953), though they retain Zeuner's idea of cool summers at 65° north latitude, do not think of an ice age as necessarily a cold age. Willett avoids the term Flint (1953) has chosen, the "thermal maximum", and calls it "the climatic optimum". In fact Bell and Willett point out that a general earth cooling would reduce atmospheric moisture and thereby cloudiness, air circulation and storminess, producing the opposite effect of glaciation! Willett prefers instead a heating, a selective variation and concentration of heat reception as a result of a steady moderately disturbed state of the sun. These conditions lead to increased moisture uptake at the equator and increased circulation, carrying moisture as clouds north to collect and produce increased cloudiness and storms at mid and high latitudes. These are refinements of Simpson's (1937) first hypotheses of a gradual heating which produces two glaciations. Under these conditions the mid-latitude maximum cyclonic precipitation (storms) extends 15° farther south into the more or less dry and settled weather area of the subtropical highs and by the same effects the equatorial rains are restricted. The zonal westerlies and the jet stream of the upper atmosphere are intensified. Storm tracks are displaced south and the storms are more frequent, producing the pluvial period.

What is responsible for the coincidence of the southern borders of the several ice sheets?

The general discussion presented by Brooks (1949) suggests on climatic evidence that if the polar ice cap grew another degree of latitude in radius it would advance as a result of intrinsic forces until it met major climatic resistance. He says the ice sheet would extend to about 40° North Latitude where it would meet

warm climates that would prevent the ice from advancing further south. Flint (1953) points out that the similarity of termini of the major ice sheets indicates a similar controlling deterrent to their further expansion (as is assumed in C. E. P. Brooks' discussion). Warmth is the effective agent in the northeastern United States. Presumably, then, other than local effects from the ice, the general warmth that halts the ice advance would govern the climate at its border.

We are left with a relatively cool (but not cold) and wet climate at the borders of the ice in the northeastern United States and maritime Canada which would allow a narrow zone of arctic conditions reflecting the glacial anticyclones. These conditions make it readily conceivable that forests similar to those of the deciduous forests of eastern North America survived rather near the ice front on well-drained, stable soils. Such survival does not require the absence of considerable areas of soil instability in the uplands and on poorly drained slopes.

The climatic conditions as suggested in this way indicate treeless areas on the mountains of New England, the Adirondacks, Appalachians and south to the Great Smoky Mountains, with forests *largely* of Spruce and Fir on the cold slopes below them. The southern extension of these trees is probably correlated with cool summers as E. Dahl suggested for southern limits of alpine plants in Scandinavia (1951), among other factors. But the extension is not as a mantle of coniferous trees covering all the central states, rather as deciduous trees in patches and sheltered lowlands mixing into the coniferous forests south and east of the mountains. Mixed deciduous and coniferous trees in combinations we do not know today must have existed on the exposed coastal plain in the north, the piedmont and lowlands in the southeast, in the Mississippi embayment and shallow areas in the northern Gulf of Mexico. Many deciduous trees probably survived in warm valleys in the central and southern part of the present deciduous forest area, while the present coastal plain flora moved only a little south.

The forests of that time were greatly changed from what we now know and species grew together in combinations not present in our forests. The climate was greatly different from any we know and to think in terms of present vegetation associations and zonations persisting intact then is unjustified. It leads to

the conviction on the one hand that the forests existed intact *in situ* and on the other that if Spruce and Fir forests mantled the southern states the Deciduous Forests must have been in Mexico. In contrast these Alaska studies as well as recent pollen spectra indicate that a conglomeration of tree species existed all together there, which species are widely separated in different associations now. Similar to the familiar pattern of migrations of birds, some species evidently migrated a long way from their present northern limit, while those now limited to the southern states probably moved only a little farther south and the two populations existed together in forests very rich in species.

These conclusions are supported by the fundamental ideas of Fernald's (1925) suggestions of plant persistence in the Gaspé-Newfoundland area and the now submerged areas of the coastal plain. They agree with Braun (1951, p. 145) in parts of her contention of survival of a mixed Tertiary forest in the near neighborhood of the continental ice sheet margin. These suggestions indicate availability of the land surface for persistence of forests. Instead of persistence of forests as we know them, I would prefer to suggest that a mixed forest resulted. This was repeatedly modified by migration and mingling of forest species with the changing climates. Migrations of forests south during ice advances would add to the richness of these mixed forests in the central refugium from which segregation of forest types has taken place since then by migration of species. In fact the Lake Forest (Hemlock-White Pine, Canadian zone) and boreal forests can be considered as segregates from mixed forest of glacial time.

These suggestions support the presence of mesophytic plant species near the ice limits at the margins of the continental sheets. They are not consistent with the thinking of many pollen analysts and students of Pleistocene geology. The concepts of many of these students have been largely inherited from European studies (Deevey, 1949). In Europe, the conclusion reached that there were large areas of tundra is supported by floristic studies, by paleobotanical examination of the Allerod deposits, by the physiography of northwestern Europe, and by the regional geology which did not permit a reservoir of temperate populations to exist a short space beyond the ice margins. Temperate populations were trapped in trans-Alpine localities, and many remain trapped there today. There is no such evidence from the northeastern

United States. These conclusions in no way contradict the suggested occurrence of boreal forest trees far to the south of their present distribution. On the contrary, it is in keeping with the importance of local microclimates. Exposed areas far to the south would be expected to show bitter local climates.

Pollen analysts have been searching for clear indication of a tundra zone in New England with negligible success. Even deposits that rest on Tazewell till in southern New England do not show the "tundra — forest tundra — tundra" that Deevey (1953) says should be there. In fact the best evidence points only to local and questionable tundra. As Deevey says, "forests appear to have lived much nearer the ice in North America, so that an abundance of forest tree pollen masked the evidence of tundra".

These speculations apply to the climatic conditions at the margin of the substages of the last (Wisconsin) ice, Iowan or Tazewell in Potter County and probably Cary at the Harvard Forest. Serious misunderstanding has resulted in the past from not defining this. When Fernald referred to the unglaciated areas of Newfoundland as untouched by the ice, as if there were but one glaciation, he never showed he knew better. Similarly the geologists who have proven his sweeping statement wrong should realize that for the value of Fernald's suggestion, Nebraskan, Kansan or Illinoisan ice covering Newfoundland is of little if any significance. But the farther removed the area from the immediate vicinity of the ice front the more probable it is that the generalizations of plant persistence will apply to the whole Pleistocene Epoch. Thus, in the Cumberland Plateau Region the suggestions of persistence probably apply to all of the advances.

3) THE RELATIONS OF THESE PHENOMENA TO THE CONCEPT OF CLIMAX IN VEGETATION

The third of the botanical implications applies to the fundamental theories of the way plants associate together. The discussion of these will first examine the general concept, then the development and uniformities of plant associations, the historical position of the formulation of the concept of Climax and finally analyses specific to the vegetation studied in Alaska.

A) General Examination of the concept

The concept of climax has been widely discussed since it was first presented about the turn of the century (Hult, 1885 and

Schimper, 1898, Cowles, 1901). Within the concept of climax is the idea of succession, a much older idea whose roots go back to Kerner (1863) and are in classical writings such as those of Theophrastus. In America the idea of succession goes as far back as Thoreau (1860) and Belknap (1792). These concepts were developed to their full logical implications and complexity by Clements (1916, 1936).

It seems to be the unfortunate fate of such a widely accepted and popularized theory that its original conception is soon so modified that it is not recognizable. As with Darwinism and the 19th and 20th Century controversy over mechanism vs. vitalism, each individual has his own "real climatic climax concept", and many of the later ones resemble the original only remotely (Tansley, 1935, 1939; Whittaker, 1953). The climax idea remains a convenient system for the description of vegetation, however, and as such has been used by recent students of vegetation in Alaska. For example, Hultén (1941) refers to the interior forest as a White Spruce and Birch forest and Stoeckeler (1949) refers to the climax White Spruce and Birch forest established on the high, dry floodplain approximately 175 years after deposition. But Stoeckeler also refers to climax Black Spruce muskeg on wet, fine-grained materials, and includes no discussion of a time relation between these two. In this he has accepted a modified climax concept which includes a physiographic climax that Clements would call a serclimax.

To Clements the climax was the mature organism, the end product of successional development, and many Continental plant sociologists treat vegetation as uniform and integrated as if an organism. A. G. Tansley represents a departure from this scheme and has come to speak for a large part of the English plant ecologists.

The climax to Tansley (1935, 1939) is any stable community, organized, mature and homogeneous under the existing conditions no matter what controls those conditions. They may be edaphic, physiographic, biotic, due to fire or mowing by man; so that succession is marked by a series of climaxes each relatively stable, differing in habitat, life form, and floristics. Tansley really uses the term climax as American ecologists use the term plant association and he uses plant association to refer to what most Americans refer to as a climax formation.

In general usage at present, the climax refers to a stable vegetation association toward which all vegetation types are moving, one which will reproduce and maintain itself as long as climatic conditions remain constant. Other characteristics such as degree of productivity, mesophytism, geographical range, and uniform, high life-form are inherent in this use.

The concept of climatic climax seems to have been based on the idea of soil stability during long periods of erosion and a gratuitous assumption that climatic conditions remain constant. These, in turn, as Cowles (1901) pointed out depend on geomorphological concepts presented by William M. Davis (1899 in 1909) concerning cycles of erosion, uplift, and deep soils of the peneplain.

Soil stability in the sense recognized in the past in temperate climates is not usable in the north because of the widespread effects of frost action (Raup, 1951). In fact, the recent work in Potter County, Pennsylvania (Goodlett, 1954) and at the Harvard Forest indicates that it does not exist in temperate climates either. H. T. U. Smith (1949) presents the best summary of the effects of frost climates on soils, and Denny (1938) describes a specific case in southern New York.

My observations in the Upper Kuskokwim River Valley indicate that the White Spruce-Birch forest of the floodplain is succeeded by a Black Spruce forest in the course of entirely natural vegetational and successional processes, and entirely natural processes (*Versumpfung* or paludification) swamp this forest in turn, and the climax is perhaps just as well considered to be the peat bogs. As has been pointed out, mapping of vegetation over an area of 8,900 square miles in the region shows that about 60% of the land surface is forested with Black Spruce. If, in the changing sequence of vegetation associations, one type is more stable than another, it should occupy an increasingly larger area with the passage of time. According to this, the sedge meadows and high brush bogs are as certainly the climax as the White Spruce and Birch forests. These contradict any consistent use of the climatic climax as understood in the recent writings.

In this way the behavior of fine-grained saturated sediments on freezing and thawing contributes to soil instability, controlling the succession of forest types and bogs. Pergelation and Depergelation (Bryan, 1946), factors of the environment which are not

purely edaphic, obliterate the logical climax forest and lead succession toward a less mesophytic, less productive vegetation of lower life-form classification. Instead of attaining any maintained equilibrium, the forests are in a state of change extending over an indefinite period of time, without necessarily any change in climate.

This may be what Watt (1947) was getting at, but it is not clear. He includes forces of integration (towards order) with those of disintegration (towards disorder) in the community at the same time. The processes remain constant while phases change and yet the whole community remains essentially the same. Elsewhere, specific studies in nearly all major vegetation types such as Richards (1952) in the tropical rain forest, Shreve (1942) in the American deserts, Gleason (1926) and Cain (1947) in the deciduous forests of temperate America, and Griggs (1934) in the Arctic, have led their authors to reject the use of the climax concept. Recently Malin (1948), an historian, by a review of the problems and results of authors applying the climax concept to the "type locality", the grasslands, proves better than any argument could how theoretical and abstract it is.

The studies of vegetation made in the Upper Kuskokwim River Region support in detail the conclusions Gleason reached about plant associations (1917, 1926) and succession (1927). In these papers Gleason points out that a plant association is the expression of overlapping and complementary physiological requirements of those species of plants which can successfully grow on the site, are not excluded from the site by growth of other plants, and whose seed source is available. Succession is the result of constant migration of individual plants into the site, of which some can become established so that some previously present species becomes eliminated. He argues against homogeneity of associations either locally or over distances.

Tansley's climax concept appears to lie between that of Clements and this of Gleason, but where can the line be drawn? Does Tansley's mowing climax last the life of one farmer, or one method of farming? Where is it separated from any group of plants one sees in nature which is stable during the lifetime of the plants growing there? Where can this be separated from the longer periods of stability due to grazing of wild animals, and, as Gleason (1927) said, from the longer periods in physiographic

and climatic change, from those slowly changing as a result of migration of new species from distant dispersal centers (Gleason, 1917), or from changes due to species evolution (Cooper, 1926)? Yet the majority of ecologists still subscribe, if not to the organismic concept, to ideas which presuppose the organic, that is, development. For example, ecologists still refer to forces in the environment which prevent the development of the climax with the consequent maintenance of a subclimax stage.

Many Americans carry it further and use the climax expanded to include animals in the biome. How can there be a biome, a spruce-moose association of continental extent if there is any reality to the complex history, soil age, origin and migrations of flora from refugia as clearly shown for the Lake Athabaska-Great Slave Lake Region by Raup (1946)? Some zoologists, as Pitelka (1941), have rejected the biome but these men did not go far enough in their analysis and see that the absence of fit applies just as well to plant groups. Perhaps Pitelka's fault is only misplaced respect for plant ecologists. Tansley (1935) rejects the concept of the biotic community but does not carry this through to the vegetation.

Perhaps one of the chief reasons Clements' classification has persisted and probably will continue to persist with those who look for a system of description, is that it has been thought all the way through. Thus, once vegetation is fitted into Clements' system, the classification is done. In the succession to the climax once started, the vegetation is swept along in the stream and once placed in the stream all is explained. Gleason's system demands that the author interpret and come to understand what he sees. Description only points to the need for understanding the processes at work.

Papers by Hopkins and Sigafoos (1951), Stout (1952, Warren-Wilson (1952), Goodlett (1954) look into what it is in the soil and external forces which make the vegetation what we find, rather than suggesting that it is that way because it is at that certain point in the stream of "development".

B) Examination of the ideas of development and uniformity of plant associations

The use of the term or idea of climax indicates by definition or by implication that there is development or increase of

organization or integration in successional sequences, such as the zonations of the depositing slope of the floodplain or those of the shelving shore of a silt-bottomed lake. The idea of development is important. Development to Clements was the embryology of the superorganism, the progress along a unidirectional path of changes of vegetation, each stage of which prepared the way for the next.

"Succession is the process of the reproduction of a formation, and this reproduction process can no more fail to terminate in the adult form in vegetation than it can in the case of the individual plant". (Clements, 1916).

European ecologists, in common with most American ecologists, have discarded the idea of the association as an organism, but the idea of development is actively retained (Tansley, 1939, 1953), and with it the idea of relatively rapid development toward an equilibrium which is maintained over a long time.

For Tansley (1935), development is the progressive maturing of vegetation, its integration or establishment of consistent internal relationships producing homogeneity. To him, development is a particular type of succession and centers around changes in the stable habitat due to biotic factors acting under uniform conditions. In this, only organically controlled succession is development.

Tansley's description of the development of marshes, fens and bogs in England is convenient for examination. Succession and development should be found in wet areas, the hydrosere of developmental classifications as Tansley has suggested himself. For this reason I want to discuss development and uniformity in plant associations and specifically their application to wet areas. The best studies of bogs have been made in Europe, using the system of plant sociology which is based on Clements' logical system. For this purpose the difference of points of view within the European schools, the Scandinavian vs. British vs. Montpellier on the nature of an association, are omitted, because they all include as a basic assumption the idea of uniformity of associations and the idea of development of vegetation. Among them, the differences seem to lie in terminology for the associations.

At first, bog-vegetation changes seem to support an idea of succession, and this seems especially to be true of the hummock growth of raised bogs. But the final product and total growth

of the raised bog perpetuate all the phases of the succession and there is no effective change to a stable "climax vegetation" at all. Instead, the climax is the whole gamut of successional stages. That there is sequence or zonation of wet-dry requirements is obvious, and that certain species of sphagnum will colonize a site only when it has been made less wet through the growth of more hydrophytic species is a direct corollary. But this is not development because the wet-site sphagna colonize low areas in the new, higher surface and supplant the dry-site sphagna just as they in their turn are supplanted (Osvald, 1923).

In fen vegetation, as described by Godwin and Bharucha (1932), increasing dryness allows the invasion of woody plants into *Phragmites* reed-swamps to form carr. At Wicken Fen, Cambridgeshire, England, it has been suggested that the limiting factor is the height of water level in winter. This high water level is so close to the low-water level of summer that even Tansley (1939, p. 767) finds it hard to suggest that there is "development" involved. There is not enough change in the volume of organic materials on the site.

The second concept inherent within the plant sociological use of the idea of the association is uniformity of the vegetation. This is at the heart of the European terminology in plant sociology. That a name such as *Callunetum* or *Sphagnetum* is applied to a vegetation association (community of Tansley's usage) indicates uniformity. "The indicator species" as a term implies a collection of conditions which are repeatable. This seems to grow out of the early 20th century botanical concept of a species as a type specimen without consideration of it as a variable population. Both botanists and zoologists now conceive of species, subspecies or varieties as variable populations, not as a series of morphological criteria represented by a type specimen. Aggregations of taxa into associations should include, then, an idea of combinations of variations. If, on this basis, a *Sphagnetum* is conceived of as all the variable conditions possible in a bog, it is a justified idea, but not a much better term than sphagnum bog. As soon as a more specific term is presented, such as *Callunetum*, the problem arises of resolving within it all the various combinations of species possible under the conspicuous presence of *Calluna*. The implicit idea (which is in the term taxon) of a repeatable expression of definite structure constantly presents itself.

Gleason pointed out that this homogeneity does not occur in space. Why then can it be assumed to occur in time? If there had been homogeneity of vegetation associations in the past there would have been selective advantage for animals to have a species-defined habitat and the biome to be a reality. But Pitelka (1941) shows this to be a fallacy and Tansley (1935) rejects the biotic community. This in itself argues for the lack of homogeneity of a community or association of plants in the past in the "state of nature" as well as in the present under man's disturbing influence.

C) Historical position of the climax in the study of vegetation

Developmental stages of the organism being integrated toward the climax is justly credited to Clements. If succession, which Clements so emphasized without the deterministic goal of development to climax, is to be used, both it and climax are misleading. For instance, when Cowles first presented the idea of the dynamic basis of plant society or association classification, he did so carefully separating the factors of climate from those of physiography. He indicates that physiographic factors can have more local influence than climate, and that retrogression is an important part of the changes of vegetation.

Although the general trend is towards mesophytism, it is not universal. Cowles says:

"The condition of equilibrium is never reached and when we say that there is an approach to the mesophytic forest, we speak only roughly and approximately. As a matter of fact, we have a variable approaching a variable, rather than a constant."

He further includes the idea of development, but bases it on physiographic changes from youth to maturity and old age of the cycle of erosion (1901, pages 78-81). In other words, the changes are correlated with changes in the physiographic or edaphic conditions, and the plant associations are the pawns of the geological changes. Cowles does not build his structure on the changes which plants create in their environment as if these changes prepare the way for the succeeding generations of plants in a determined direction of succession. He says that the order of change of topographic forms runs according to well defined laws (those of W. M. Davis, 1909); so plant succession must

be in orderly fashion adapted to the new conditions. It was Clements who first brought in the concept that out of certain historical causes definite effects can be forecast. The difference is one of innate process determining the final goal of vegetation, as opposed to vegetation changing according to the changes in its edaphic surroundings. What Clements brought was determinism, a philosophy deeply rooted in mechanistic scientific thought of the early 20th Century. Determinism has come under more and more criticism in all kinds of fields since then, and attacked at its philosophical heart by Whitehead (1925), long after Hume first objected. Once the determinism which Clements put in has been eliminated, there is no essential disagreement between the ideas presented by H. C. Cowles and H. A. Gleason, and they are consistent with those of Warming and Kerner.

Clements should not be thought of, though, in this absolute comparison with what has been learned since his time. He represents a revolt against the widespread idea in America that certain areas of vegetation were abnormal, such as the grasslands. Malin points out how the prairies were considered as inadequate in many ways and the continuation of such thinking exists in the great American myth of the Great American Desert. Clements and men of his time were emphasizing that vegetation was natural to a certain type of climate. The trend of philosophic thought at the turn of the century was deterministic and regional in geography and his conviction of the naturalness of vegetation types led Clements into conviction of the correctness of deterministic thinking. At that time political and sociological thinking were also emphasizing stability and equilibrium after the Industrial Revolution and 19th Century wars and before World War I. He became the spokesman for that group because of his ability to explain his subject.

Criticism of his contributions is empty. And his contributions are many, but like many other scientists his contributions were not the ones he thought most important. For the reasons presented here that the terms are misleading and do not contribute to an understanding of vegetation I have dropped completely the words Climax, successional, development, biome, sere and the words associated with them. It should be realized, however, that Gleason published his objections to Clementsian doctrine in 1917, as soon as Clements large book appeared (1916). In this contemporaneity

Gleason's clear contributions cannot be regarded as an historical development growing out of additional knowledge, but rather as the result of greater insight and better understanding.

D) Specific analyses

Returning to the problem of the vegetation of the bogs in the Upper Kuskokwim Region: the cyclic processes in operation in the bog areas indicate and emphasize that the vegetation of boreal and arctic regions can be understood better and must be studied against a background of the history of land surfaces, of vegetational migrations, of the intrinsic variability of the small number of plant species, and of geomorphic processes such as cryoplanation and cryoturbation. These are not the only factors but each of them has an important effect on the nature of the substrate, the flora, and the condition of the surface at the time of plant establishment.

Certain of these forces can be seen in action in the bogs. They are responsible both for the kaleidoscopic patterns of the vegetation and for the type of order that exists. The physiological variability of the species of plants, the small number of species, the youth of the arctic and subarctic vegetation (not flora), the disturbance of the substrate by soil frost, and the flora are discussed in the following paragraphs.

First: Morphological variations in many of the genera of the north such as Salix, Betula and the grasses occur in the same way that random genetic recombinations do. Certain combinations of characteristics appear without regard for areal segregation or plant geographical patterns. Others occur as clines across the north, or as isolated particular combinations. At the same time other populations are very limited in variation. All of this has led to naming of many varieties, hybrids and questionable species. There is no reason to expect that physiological variation should appear in ways different from the morphological patterns.

Repeated isolation and reassembling of populations correlated with climatic changes of the numerous ice advances seems to have produced much heterozygosity in some of these populations and very little variability in others. Their behavior is very well explained by the genetic and evolutionary processes suggested by Mayr (1954) of variable gene backgrounds and effects of populations subjected to temporary isolation. This leads to the

fact that morphologically defined species populations occupy a wide variety of microclimates and thus enter several plant associations. Because of varied degree of success in competition in these several habitats, they appear in all degrees of conspicuousness.

As one moves through an area of "bog" or "low tundra", first one species is primary and then another; then a combination of these three, then these other three. There may be a total of only 25 species involved and 20 species present at any and all sites, and in nearly all possible combinations. Each different combination of environmental requirements allows certain ecotypes to occupy the area: for example, while *Carex lugens* is primary in a wet hollow in the tundra in one spot, it may be primary in sphagnum under forest on sandy alluvium in another. The plants are the same morphological species population but quite different ecotypes (physiological variations or races within the species population). Yet a slight change in either habitat may allow another species such as *Eriophorum vaginatum* to take over and nearly eliminate the *Carex*. At each site different requirements overlap in different ways. Each recombination of environmental factors, such as variations in moisture, temperature or exposure, allows some species to be included in the association and excludes others. In some places variations that are only slight will eliminate a certain species while in others what seem to us to be fundamental habitat variations seem to have no important effect. It seems that physiological variation within the species is often greater than that between two species.

Second: Because there are few species, those species which can survive have a variety of habitats available to them. Interspecific competition is not so marked, or, better, there are not as many different kinds of competitors. Instead of interspecific competition, competition is between ecotypes, and the results do not appear in floristic lists.

Yet the microclimates of the North are as variable as those of more southern areas. Such variations cross the limits of tolerance of certain species or physiological variants and enter the tolerance limits of others. With only a few species available, recombinations of these species in all possible ways result, with certain ones becoming conspicuous here and others there so that the vegetation seems disorganized or weedy (Griggs, 1934). The number of species is not adequate to provide different species

names to describe each habitat, but the recombinations represent real features in the vegetation and habitat. They are just distasteful to those trying to arrange an orderly classification. If new species were added to the lists at each site a new association would be named and accepted.

The general vegetation discussions of Antevs (1932) and Polunin (1934-5, 1948) show the problems of rationalizing these difficulties in preparing a regional description of the vegetation similar to those prepared for temperate regions. Tansley indicates meeting with this problem in his discussion of Arctic-alpine areas and Blanket bogs (1939).

The effect is probably the result of numbers simply. The number of species in the total flora, if plotted against latitude, increases following an "S-shaped" curve from high latitudes towards the tropics. On the other hand, the number of individuals of any one species decreases following an S-shaped curve from high latitudes towards the tropics. In the middle latitudes, where these lines are roughly parallel, plant associations assume a regularity of sorts, and have been attributed qualities of organismic reality. In the north endless variations occur among a few species. At the southern end the same problem exists but for a different reason. As Cottam, Curtis and Hale (1953, p. 755) put it:

"In Tropical rain forests, with 60 to 90 species per hectare (Black, et al, 1950) the number of quadrats or points needed for even reasonable accuracy becomes impossibly great.... This failure of the usual sampling methods to give accurate determinations of such a basic, simple characteristic as relative composition is no doubt responsible for the emphasis placed by the Tropical ecologists on physiognomic classification (Beard 1944, Richards 1952)".

On this basis the suggestion of Braun-Blanquet that the vegetation of the North is simple and that of the Tropics highly complex and organized seems to make no sense. The difference is one of the number of species available, and when it has been said that the vegetation of the North is less well organized or simpler, what has been meant is probably that it is made up of fewer species. It certainly is not simple.

Third: The short periods of time available for migrations of plant associations since the exposure of the land over large areas of the North have not provided opportunity for species to settle out into their "normal" or "equilibrium" relations with each

other. In other words, with the intrinsic problems described in 1) and 2) which require variable associations in the description of plant cover, there is the additional complication that the plants have not yet settled down in their inter-relationships, if they ever do. Although the species found in the North may be old, it cannot be doubted that their combinations are new to the areas they now occupy. The same is certainly true for bog vegetation within the forested regions. Gleason (1926) has suggested that increased uniformity of "mature" vegetation types or associations is a result of the elimination of species which cannot compete during long periods of migration. He uses migration to refer to persistent attempts at invasion by species from surrounding habitats. This may be called "development" of the plant association in terms of clarifying its species composition, but it is not the development towards a determined goal which Clements conceived and which those who use the term imply.

Fourth: Repeated freezing and thawing of the ground on which these plants grow churn the soil materials, inhibit the development of soil profiles, and disturb the habitat, all within the life span of the species which occupy that spot (Raup, 1951; Hopkins and Sigafoos, 1951). All species must remain adapted to disturbed conditions and be capable of "pioneering". Species comprising the vegetation cannot develop complex structural inter-relationships because species are not able to occupy the surface undisturbed.

Soil movement may destroy an individual plant of one species; then, within limits, any of the species from the surrounding vegetation will colonize the spot. To the degree that each species must retain characteristics of pioneer vegetation, the vegetation is weedy as Griggs suggested and migratory as Crampton (1912) suggested. Instead of inter-plant associational organization, most regular patterns of the vegetation are based on structured soils or other frost features which act through soil conditions such as drainage and disturbance. This produces the societies low on the sociological scale of the European phytosociological system and is in part justified, but largely an illusion.

Fifth: The flora of wet places in the Upper Kuskokwim River Region is of three quite different types: 1) that of silt-shored ox-bow lakes or sloughs; 2) that of peat bogs; and 3) that of a peat bog-invaded silt-shored slough where the two types exist in combination. Such a bog has the species from both major types and

because of its disturbed conditions has many additional species. The history of disturbance can usually be read both in the flora and in the physiography, and, obviously, changes in flora are fundamental to the vegetation patterns and life form aspect of the bog, and to the associations of plant species.

SUMMARY

The present climate and vegetation produce a water-logged condition on the fine-grained alluvial areas of the Upper Kuskokwim River Region of Alaska. Under sphagnum-Black Spruce vegetation, peat accumulates on the surface, and the underlying ground becomes frozen and remains so for a number of years. Quaking bogs form by colonization of ponds, by swamping the low areas, or by thawing into the frozen ground. They expand by thawing in many cases and coalesce, leaving islands covered with sphagnum-Black Spruce forest. The building up of peat and the appearance of the perennially frozen ground set the stage for the lowering of the surface by thawing at the margins of the advancing quaking bogs. The antagonistic processes of thawing and of rebuilding of peat combine into a physiographic process molding the terrain of the alluvial lowlands. The cycle of the replacement of forest by bogs, and subsequent reforestation, is now going on and can have gone on in the past without change in climate. Cycles of bog formation and reforestation during a period of stream aggradation of fine-grained materials or of loess deposition are adequate to explain the formation of muck. Soligenous bogs act as traps for alluvial or aeolian silts and, persisting during a period of similar aggradation, are also sufficient to explain muck deposits without repeated cycles of invasion of the forested surfaces. These two processes will form muck deposits in the valley centers where the valley slope processes cannot be functional. Such valley-center mucks have not been satisfactorily accounted for in the past, and their existence has thrown some doubt on the processes suggested for valley-side muck development. Physiographic and physical forces active in the floodplain deposits control the distribution of bogs and the patterns of bog vegetation on the bog surfaces.

Recognition of the existence of the processes described here will contribute to the understanding of the history of the Pleistocene by application to the study of Quaternary deposits, and to the interpretation of the periglacial climatic conditions for which they furnish evidence. At present the formation of bogs is an important force in the control of the pattern of vegetation in the interior of Alaska, and is contributory evidence for the development of ideas of the relation of soil instability to vegetation, and to slope processes and slope development. It is an extension of the study of cold climate periglacial geological processes from the slopes to the alluvial lowlands. The studies indicate both the persistence of bogs during periods of climatic change and the continuation of change in bog-to-forest relations in the lowlands under constant climatic conditions. The formation of peat bogs as described depends upon the luxuriant growth of sphagnum moss, which is much more abundant in forested than tundra regions. The mucks of Interior Alaska that were developed by cycles of bogs suggest a boreal (forest) rather than arctic (tundra) environment for their deposition.

THE FLORA OF THE BOGS

In listing the flora, a compromise must be made between the tendency to list only those plants that are a conspicuous part of the vegetation type and the temptation to list all species that possibly can be squeezed in. The list of flora of these bogs is complicated by the infiltration of the Alaska Range in the areas of glacial till and outwash from the Alaska Range.

In the following list, those plants that are considered proper members of the bog flats are unqualified. Those that are part of the Alaska Range Flora, are marked with (a). Those that grow in ponds or puddles or on the floor of the black spruce muskeg and thus are not really characteristic of the flats are marked *. The floras of J. P. Anderson (1943—1952) and E. Hultén (1941—1950) were used as a starting point in identifying the higher plants. Documenting specimens of the plants will be deposited in the herbaria of the United States National Museum, the Harvard Herbarium, the National Museum of Canada and the Riksmuseet at Stockholm.

Lichens

I have not attempted to list the entire lichen flora of the bogs. All of the lichens grow in the muskegs on the drier *Sphagnum fuscum* hummocks or on living or dead trees. Species identifications of my collections were made by Lucy Raup.

STICTACEAE

*	Sticta pulmonaria (L.) Hoffm.	on dead trees

PELTIGERACEAE

*	Peltigera aphthosa (L.) Willd.	on hummocks and stumps
*	Peltigera canina (L.) Willd.	on hummocks and stumps
*	Nephroma arcticum (L.) Torss.	on moss hummocks

CLADONIACEAE

*	Cladonia alpestris (L.) Rabenh.	between or on hummocks
*	Cladonia rangiferina (L.) Web.	between and on hummocks
*	Cladonia sylvatica (L.) Hoffm.	do.
*	Cladonia sylvatica (L.). f. sylvestris Oed.	do.
*	Cladonia deformis (L.) Hoffm.	on *Sphagnum* hummocks and on stumps
*	Cladonia amaurocraea (Flk.) Schaer.	between and on hummocks
*	Cladonia uncialis (L.) Web.	do.
*	Cladonia elongata (Jacq.) Hoffm. — C. gracilis (L.) Willd., var. elongata —	do. (more common under White Spruce)
*	Cladonia lepidota Nyl., f. cerasphora	on *Dicranum* and on stumps
*	Cladonia pyxidata (L.) Fr.	on dead trees
*	Cladonia cyanipes (Sommerf.) Vain., f. Despreauxii (Bor.) Th. Fr.	between and on hummocks
*	Cladonia gracilis (L.) Willd.	do.

PARMELIACEAE

*	Parmelia physodes (L.) Ach.	on dead spruce and birch branches
*	Parmelia saxatilis (L.) Ach.	do.
*	Cetraria islandica (L.) Ach., var. Delisei (Bory) Ach.	between and on hummocks
*	Cetraria islandica (L.) Ach., var. platyna (Ach.) Th. Fr.	do.
*	Cetraria cucullata (Bell.) Ach.	do.

USNEACEAE

*	Usnea longissima Ach.	on dead branches
*	Alectoria jubata (L.) Ach.	do.

Mosses

This list, again, does not claim to be complete. However, as most of the bogs are characterized by their peculiar species of mosses, the list is complete as far as the mosses that take a real part in the progress of development are concerned. The species of Liverworts and Mosses except for *Sphagnum* were identified by Dr. Wm. C. Steere, Jr. A field reference herbarium was made, using specimens he identified, and all field identifications were referred to those standards.

POLYTRICHACEAE

*	Polytrichum commune Hedw.	in muskegs or tractor-trails
*	Polytrichum juniperinum Willd.	do.

DITRICHACEAE

*	Ceratodon purpureus (Hedw.) Brid.	tussocks and logs, grass slough
	Distichium capillaceum (Hedw.) Bry. Eu.	drained till pool

DICRANACEAE

*	Dicranum Bergeri Bland.	muskegs
*	Dicranum elongatum Schleich.	do.
*	Dicranum fuscescens Turn.	do.
*	Dicranum scoparium Hedw.	dry muskeg
	Oncophorus Wahlenbergii Brid.	drained till pool, rotting wood

POTTIACEAE

(a)	Didymodon rufus Lor.	drained till pool, Probably present because of the mineral soil
(a)	Tortella fragilis (Hook. & Wils.) Limpr.	do.
	Trichostemum cuspidatissimum Card. & Ther.	do., primary moss; primary also in many *Myrica-Scirpus* areas

SPLACHNACEAE

	Splachnum luteum Hedw.	on moose droppings anywhere

AULACOMNIACEAE

(a)	Aulacomnium acuminatum (Lindb. & Arn.) Paris	muskeg
	Aulacomnium palustre (Web. & Mohr.) Schwaegr.	floodplain slough and recently invaded bogs
*	Aulacomnium turgidum (Wahlenb.) Schwaegr.	muskeg and grass slough

BARTRAMIACEAE

(a)	Catoscopium nigritum Brid.	drained till pool

MEESIACEAE

*	Paludella squarrosa (Hedw.) Brid.	grass slough

MNIACEAE

*	Mnium affine Bland.	stumps

HYPNACEAE

*	Calliergon cordifolium (Hedw.) Kindb.	grass slough in forest
*	Calliergon giganteum (Schimp.) Kindb.	do.
*	Calliergon stramineum (Brid.) Kindb.	do.
	Campylium stellatum (Hedw.) Lange & C. Jens.	primary. *Myrica-Scirpus* areas
*	Climacium dendroides (Hedw.) Web. & Mohr.	edge of grass slough. forest
	Drepanocladus aduncus (Hedw.) Warnst.	bog pool invaded by flats. and *Myrica-Scirpus* areas
	Drepanocladus exannulatus (Gumb.) Warnst.	pool in muskeg
*	Drepanocladus badius (Hartm.) Roth	old floodplain slough
*	Drepanocladus fluitans (Hedw.) Warnst	muskeg in tufts. and floodplain pool
	Drepanocladus revolvens (C. Mull.) Warnst.	primary. *Myrica-Scirpus*. *Carex vaginata* areas
*	Drepanocladus uncinatus (Hedw.) Warnst.	dry muskegs
*	Hylocomium splendens (Hedw.) Bry. Eu.	muskegs
	Hypnum Bambergeri Schimp.	*Myrica-Scirpus* areas, primary
*	Hypnum callichroum Brid.	invaded floodplain pool
*	Hypnum Lindbergii Mitt.	grass slough in forest
*	Hypnum subimponens Lesq.	muskeg
*	Pleurozium Schreberi (Willd.) Mitten	muskeg
*	Ptilium Crista-castrensis (Hedw.) de Not.	muskeg
*	Rhytidiadelphus triquetrus (Hedw.) Warnst.	muskeg
*r	Rhytidium rugosum (Hedw.) Kindb.	white-black spruce forest
	Scorpidium scorpioides (Hedw.) Limpr.	primary in *Carex vaginata*. *Scirpus-Myrica* areas
	Tomenthypnum nitens (Schreb.) Loeske	invaded flood-plain sloughs

LESKEACEAE

*r	Thuidium abietinum (Brid.) Bry. Eu.	muskeg

SPHAGNACEAE

I identified the mosses of this family using A. LeR. Andrews's key (1913). They are the critical elements in the development of the bogs. All are found within the bog areas. but certain ones are characteristic of marginal area such as recently invaded ponds or old floodplain sloughs. These are marked *; the very scarce species are marked r.

r	Sphagnum imbricatum Hornsch.	emergent, sedge meadows, brush
	Sphagnum magellanicum Brid.	do.
r	Sphagnum palustre L.	do.
	Sphagnum papillosum Lindb.	do.
	Sphagnum compactum DC	do.
*	Sphagnum subsecundum Nees	grassy sloughs, ox-bows
	Sphagnum Ångströmii Hartm. f.	invaded ox-bows, beaded drainage
*	Sphagnum squarrosum Crome	wet holes in muskeg
	Sphagnum teres (Schimp.) Ångstr.	invaded ox-bows, beaded drainage
	Sphagnum balticum Russow	emergent, sedge meadows, brush
	Sphagnum Dusenii C. Jens.	submerged or emergent, sedge meadows
	Sphagnum Lindbergii Schimp.	do.
*	Sphagnum obtusum Warnst.	grassy sloughs, ox-bows
r	Sphagnum pulchrum (Lindb.) Warnst.	emergent, sedge meadows, brush
	Sphagnum recurvum Beauv.	do.
	Sphagnum riparium Ångstr.	do.
*	Sphagnum capillaceum (Weiss) Schrank	muskegs
	Sphagnum fuscum (Schimp.) H. Klinggr.	brush areas and muskegs
r	Sphagnum plumulosum Roll	do.
r	Sphagnum quinquefarium (Lindb.) Warnst.	brush areas
	Sphagnum rubellum Wilson	brush areas and muskegs
	Sphagnum Warnstorfii Russow	do.
r	Sphagnum fimbriatum Wilson	muskeg wet holes
*	Sphagnum Girgensohnii Russow	muskegs
r	Sphagnum robustum (Russow) Roll	brush and muskegs

HEPATICAE

MARCHANTIACEAE

*	Marchantia polymorpha L.	exposed silt under slumps
*	Conocephalum conicum (L.) Dumort.	do.
*	Preissia quadrata (Scop.) Nees	

PTILIDIACEAE

	Ptilidium ciliare (L.) Nees	*Sphagnum fuscum* brush and muskegs

CEPHALOZIACEAE

	Cladopodiella sp.	do.

HARPANTHACEAE

*	Mylia anomala (Hook.) S. F. Gray	do.

JUNGERMANNIACEAE

*	Gymnocolea inflata (Huds.) Dumort.	wet *Carex* tufts in muskeg

SCAPANIACEAE

*	Scapania sp.	do.

Vascular Plants

EQUISETACEAE

*	Equisetum sylvaticum L.	muskegs
	Equisetum fluviatile L.	wettest bogs, especially old ox-bow sloughs and beaded drainages.
	Equisetum fluviatile L., f. Linnaeanum (Döll) Broun	do.
@	Equisetum palustre L.	pools or *Scirpus* areas
@	Equisetum scirpoides Michx.	brush and muskegs
*	Equisetum arvense L., var. boreale (Bong.) Ledeb.	muskegs

LYCOPODIACEAE

*	Lycopodium annotinum L., var. alpestre Hartm.	muskeg

PINACEAE

*	Larix laricina (Du Roi) K. Koch, var. alaskensis (Wight) Raup	wettest muskegs and bog ridges
*	Picea glauca (Moench) Voss, nearest to var. albertiana (S. Brown) Sarg.	rare in dry muskegs or at high altitudes
*	Picea mariana (Mill.) Britton, Stern & Pogg.	muskegs and bog ridges

SPARGANIACEAE

*	Sparganium angustifolium Michx.	pond in muskeg
*@	Sparganium hyperboreum Laest.	pond in till, muskeg
	Sparganium minimum (Hartm.) Fr.	pool in bog

ZOSTERACEAE

*@	Potamogeton alpinus Balbis, var. tenuifolius (Raf.) Ogden	pond in till, spruce forest
	Potamogeton epihydrus Raf., var. Nuttallii (Cham. & Schlecht.) Fernald	pool in bog
	Potamogeton gramineus L., var. maximus (Hartm.) Fr.	pool in bog
	Potamogeton natans L.	pool in bog
*@	Potamogeton perfoliatus L., var. Richardsonii Benn.	pond on till in spruce forest
*	Potamogeton vaginatus Turcz.	clear streams

JUNCAGINACEAE

	Triglochin maritimum L.	bog hollows
*	Triglochin palustre L.	*Myrica* area
	Scheuchzeria palustris L., var. americana Fernald	bog hollows

GRAMINEAE

*	Alopecurus aequalis Sobol., var. natans (Wahlenb.) Fernald	pond in muskeg
*	Arctagrostis arundinacea (Trin.) Beal	muskeg
	Agrostis alaskana Hultén	brush
	Agrostis scabra Willd. variation includes var. geminata (Trin.) Hultén	do.
	Calamagrostis canadensis (Michx.) Beauv., var. scabra (Presl) Hitchc.	edges of bogs, ox-bow sloughs
	var. robusta (Vasey) Stebbins	variation includes both varieties
*	Deschampsia caespitosa (L.) Beauv., var. glauca (Hartm.) Sam.	brook margins
*	Poa arctica R. Br.	muskeg
*	Arctophila fulva (Trin.) Anders.	silt of brook through muskeg
*	Glyceria maxima (Hartm.) Holmb., ssp. grandis (S. Wats.) Hultén	silt bottomed ponds, ox-bows
*	Glyceria borealis (Nash) Batchelder	do.
*	Glyceria pulchella (Nash) K. Schum.	do.
(a)	Festuca altaica Trin.	brush, slope

CYPERACEAE

	Eriophorum angustifolium Honckeny (includes var. majus Schulz)	general, wetter parts of bogs
(a)	Eriophorum brachyantherum Trautv.	till hollows in bogs
*	Eriophorum gracile Koch	wet muskegs
	Eriophorum Chamissonis C. A. Meyer,	general, wetter parts of bogs
	var. albidum Fernald	variation includes both varieties
	var. aquatile (Norman) Fernald	
	Eriophorum vaginatum L. (includes var. spissum Fernald)	bog ridges or muskegs
	Scirpus hudsonianus (Michx.) Fernald	wet brush
	Scirpus cespitosus L., var. callosus Bigel.	wettest parts of bogs, oftenest in bog hollows, bare silt
(a)	Eleocharis palustris (L.) R. & S., var. major Sonder	till ponds
(a)	Eleocharis pauciflora (Lightf.) Link, var. Fernaldiana Svenson	wet slope (this is a considerable range extension from British Columbia)
*	Eleocharis acicularis (L.) R. & S., f. rigidula (Reichb.) Svenson	muskeg pool
	Rhynchospora alba (L.) Vahl	wet *Scirpus-Myrica* area (This is a range extension from southeastern Alaska)

@	Kobresia simpliciuscula (Wahlenb.) Mackenzie	wet slope
@	Carex gynocrates Wormskj.	wet slope on till
	Carex leptalea Wahlenb.	invaded ox-bow
@	Carex microglochin Wahlenb.	wet slope on till
	Carex pauciflora Lightf.	bog ridges
	Carex chordorrhiza Ehrh.	fundamental in wettest parts, esp. invaded ponds
*@	Carex bipartita Bellardi	till hollow
*@	Carex neurochlaena Holm	pools in burned muskeg
*@	Carex canescens L.	lake in till
	Carex canescens L., var. subloliacea Laestad	invaded ox-bows
	Carex brunnescens (Pers.) Poir. variation includes	old ox-bow
	var. sphaerostachya (Tuckerm.) Kük.	pool in muskeg
*	Carex disperma Dewey	pool in muskeg
	Carex tenuiflora Wahlenb.	hummocks or ridges in bogs
*	Carex loliacea L.	pool in forest
*	Carex Garberi Fernald, var. bifaria Fernald	pool in forest
*	Carex lugens T. Holm	muskeg
	Carex aquatilis Wahlenb.	usually in old ox-bows
@	Carex rariflora (Wahlenb.) Smith	wet slope and strangmoor
	Carex limosa L.	fundamental in bog hollows and sedge meadows
	Carex magellanica Lam., (variation includes C. paupercula Michx. and C. irrigua Wahlenb.)	usually in invaded ponds
	Carex livida (Wahlenb.) Willd.	bog hollows in standing water
@	Carex atrofusca Schkuhr	wet slope and till hollows
@	Carex capillaris L.	wet slope
	Carex lasiocarpa Ehrh., var. americana Fernald	margins of streams in bogs
	Carex rostrata Stokes variation includes var. utriculata (Boott) Bailey	wettest areas
@	Carex rostrata × membranacea	delta of small stream out of flats onto a silt bar
	Carex paludivagans Drury	zones of bog between *C. rostrata* and *C. rotundata*
	Carex rotundata Wahlenb.	fundamental in sedge meadows
*	Carex physocarpa Presl	wet margins of old ox-bows
@	Carex membranacea Hook.	pools in forest

ARACEAE

	Calla palustris L.	wettest parts of bog in *Sphagnum papillosum*

JUNCACEAE

*	Juncus castaneus Smith	*Scirpus* areas, ridges
*	Juncus filiformis L.	muskeg pond
	Juncus stygius L., var. americanus Buchenau	sedge meadow, brush
(i)	Juncus triglumis L.	wet slopes, till hollow
*	Luzula rufescens Fisch.	muskeg

LILIACEAE

	Tofieldia glutinosa (Michx.) Pers.	*Scirpus-Myrica* areas
*	Tofieldia pusilla (Michx.) Pers.	wet slope, low ground in forest
(i)	Fritillaria camschatcensis (L.) Ker-Gawl.	wet slope

IRIDACEAE

*	Iris setosa Pallas	old ox-bow slough

ORCHIDACEAE

	Habenaria hyperborea (L.) R. Br.	*Scirpus-Myrica* areas
*	Spiranthes Romanzoffiana Cham. & Schlecht.	muskeg
	Malaxis paludosa (L.) Swartz	wet *Myrica* brush areas, a range extension from southeastern Alaska

SALICACEAE

(i)	Salix reticulata L.	wet slope
*	Salix glauca L., var. acutifolia Schneider	muskegs
(i)	Salix Barclayi Ands.	wet slope at forest edge
*	Salix myrtillifolia Ands.	muskeg
*	Salix Bebbiana Sarg.	ox-bow sloughs, grassy
	Salix arbutifolia Pallas	brush areas, wet
	Salix pulchra Cham.	brush areas and grassy ox-bow sloughs

MYRICACEAE

	Myrica Gale L., var. tomentosa C. DC.	fundamental in flooded areas, with sparse or no *Sphagnum*

CORYLACEAE

	Betula nana L., var. sibirica Ledeb.	fundamental in *Sphagnum*-brush areas
*	Betula glandulosa Michx.	old ox-bow sloughs
*	Betula papyrifera Marsh., var. kenaica (Evans) Henry	muskegs
*	Alnus crispa (Ait.) Pursh (includes ssp. sinuata (Regel) Hultén)	old ox-bows and forest edges
*	Alnus tenuifolia Nutt.	do.

SANTALACEAE

* Geocaulon lividum (Richards.) Fernald — muskegs

POLYGONACEAE

Rumex arcticus Trautv. — brush areas and muskegs
* Polygonum alaskanum (Small) Wight — muskeg
* Polygonum viviparum L. — muskeg

CARYOPHYLLACEAE

Stellaria longipes Goldie — brush areas

NYMPHAEACEAE

Nuphar polysepalum Engelm. — ponds and lakes
Nymphaea tetragona Georgi — ponds and lakes on old surfaces

RANUNCULACEAE

* Caltha palustris L., — wet holes in muskeg
var. arctica (R. Br.) Huth
var. asarifolia (DC.) Huth — variation includes both varieties
Ranunculus Gmelini DC., — ponds, common
var. Hookeri (D. Don) L. Benson
var. yukonensis (Britt.) L. Benson — variation includes both varieties
* Ranunculus lapponicus L. — muskegs
* Ranunculus repens L. — alder slough
* Ranunculus reptans L. — shore of muskeg lake
@ Thalictrum alpinum L. — wet slope
* Thalictrum sparsiflorum Turcz., — brush on edge of forest
var. Richardsonii (Gray) Boivin

CRUCIFERAE

* Cardamine pratensis L., — *Calamagrostis* grassy slough
var. palustris Wimm. & Gräb.

DROSERACEAE

Drosera anglica Huds. — *Scorpidium-Drep. revolvens* areas
Drosera rotundifolia L. — *Sphagnum fuscum* areas

SAXIFRAGACEAE

@ Saxifraga Hirculus L. — wet slope
@ Parnassia Kotzebuei Cham. & Schlecht. — wet slope and edges of forest
Parnassia palustris L., — ox-bow sloughs or forest edge
var. neogaea Fernald

	ROSACEAE	
	Spiraea Beauverdiana Schneider	brush areas and muskeg
*	Rubus arcticus L.	muskeg
	Rubus Chamaemorus L.	*Sphagnum fuscum* areas
	Potentilla fruticosa L.	rare in the valley bottom
	Potentilla palustris (L.) Scop.	ox-bow sloughs and invaded areas
@	Dryas integrifolia M. Vahl	till hollows
@	Sanguisorba officinalis L.	*Betula-Myrica* areas
	LEGUMINOSAE	
*@	Oxytropis foliolosa Hook.	forest hollows on till
	GERANIACEAE	
*	Geranium erianthum DC.	brush margins
	EMPETRACEAE	
	Empetrum nigrum L., var. hermaphroditum (Lge.) Sør.	*Sphagnum fuscum* areas
	VIOLACEAE	
*	Viola epipsila Ledeb., var. repens (Turcz.) W. Bckr.	muskeg
	ONAGRACEAE	
@	Epilobium palustre L., var. lapponicum Wahlenb.	wet muskeg on till, wet slope
	var. grammadophyllum Haussk.	variation includes both varieties
	Epilobium palustre L., var. palustre	old, invaded ox-bow
	HIPPURIDACEAE	
	Hippuris vulgaris L.	pools and lakes
	UMBELLIFERAE	
	Cicuta mackenzieana Raup	invaded ox-bows
	CORNACEAE	
	Cornus suecica L.	brush areas
	ERICACEAE	
	Ledum palustre L., var. decumbens Ait.	drier brush and muskegs
	Ledum groenlandicum Oeder	muskegs
	Andromeda Polifolia L.	sedge meadows, brush, muskegs, fundamental in low brush areas
	Chamaedaphne calyculata (L.) Moench, var. angustifolia (Ait.) Rehder	drier brush and muskegs

Arctostaphylos rubra (Rehder & Wilson) Fernald	do.
Vaccinium Oxycoccos L.	*Sphagnum fuscum* areas
Vaccinium uliginosum L.,	general in lowland regions
var. uliginosum	variation includes both varieties
var. alpinum Bigel.	
Vaccinium Vitis-Idaea L.,	*Sphagnum fuscum* areas
var. minus Lodd.	

PRIMULACEAE

@ Primula egaliksensis Wormskj.	wet slope
@ Dodecatheon frigidum Cham. & Schlecht.	wet slopes
Trientalis europaea L.,	*Sphagnum fuscum* or
var. arctica (Fisch.) Ledeb.	*S. papillosum* areas

GENTIANACEAE

@ Swertia perennis L.	wet slope, an extension from the south coast
Menyanthes trifoliata L.	general and fundamental in wettest parts of bogs

POLEMONIACEAE

Polemonium acutiflorum Willd.	wet brush

SCROPHULARIACEAE

* Pedicularis labradorica Wirsing	muskegs
Pedicularis sudetica Willd.	*Scirpus-Myrica* bog hollows
@ Pedicularis verticillata L.	wet brush areas

LENTIBULARIACEAE

Pinguicula villosa L.	*Sphagnum fuscum* areas
Pinguicula vulgaris L	*Sphagnum fuscum* and *S. papillosum* areas
Utricularia intermedia Hayne	shallow water of bog hollows (*Myrica* areas)
Utricularia vulgaris L.,	deep water of pools
var. americana Gray	
Utricularia minor L.	pools or streams through bogs
Utricularia ochroleuca Hartm.	pools or lakes

RUBIACEAE

Galium Brandegei Gray	sedgy invaded ox-bows
Galium trifidum L.	do.
Galium tinctorium L.,	do.
var. subbiflorum (Wieg.) Fernald	

ADOXACEAE

*	Adoxa Moschatellina L.	muskeg blow-down, silt soil

VALERIANACEAE

@	Valeriana capitata Pallas	wet slope
*	Valeriana capitata Pallas, var. bracteosa (Britt.) Hultén	muskegs

COMPOSITAE

*	Solidago multiradiata Ait.	muskegs or wet slopes, especially @
	Aster junciformis Rydb.	*Calamagrostis*-invaded ox-bow
@	Artemisia arctica Less.	wet slope
	Petasites frigidus L. Fries (includes var. hyperboreoides Hultén)	wet muskeg hollows do.
	Senecio frigidus (Richards.) Less.	wet muskegs, especially @
	Senecio congestus (R. Br.) DC., var. lacerratus (Ledeb.) Fernald var. palustris (L.) Fernald	wet muskegs variation includes both varieties

The following species are regarded as characteristic of areas with shallow, shelving, silt shores, i.e. lakes and ponds:

Calliergon cordifolium	*Calamagrostis canadensis*, var. *scabra*
Calliergon stramineum	— var. *robusta* variation
Calliergon giganteum	*Carex physocarpa*
Drepanocladus aduncus	*Salix arbutifolia*
Drepanocladus badius	*Salix Bebbiana*
Drepanocladus exannulatus	*Salix pulchra*
Drepanocladus fluitans	*Alnus crispa*
Sphagnum squarrosum	*Alnus tenuifolia*
Sphagnum subsecundum	*Betula glandulosa*
Sphagnum obtusum	*Nuphar polysepalum*
Equisetum fluviatile	*Nymphaea tetragona*
Potamogeton epihydrus, var. Nuttallii	*Ranunculus Gmelini*
Potamogeton gramineus, var. maximus	*Potentilla palustris*
Potamogeton natans	*Hippuris vulgaris*

The following species are regarded as characteristic of peat bogs:

Campylium stellatum	*Scirpus cespitosus*
Drepanocladus revolvens	*Carex limosa*
Scorpidium scorpioides	*Carex livida*
Hypnum Bambergeri	*Carex rotundata*
Sphagnum papillosum	*Malaxis paludosa*
Sphagnum magellanicum	*Myrica Gale*
Sphagnum balticum	*Betula nana*, var. *sibirica*
Sphagnum Dusenii	*Drosera anglica*

Triglochin maritimum
Triglochin palustre
Scheuchzeria palustris, var. *americana*
Eriophorum Chamissonis
Eriophorum angustifolium
Andromeda Polifolia
Vaccinium uliginosum
Menyanthes trifoliata
Pedicularis sudetica
Utricularia intermedia

The following species are regarded as characteristic of the areas under the combination of influences of peat bogs invading silt bottomed ponds:

Aulacomnium palustre
Sphagnum teres
Spbragnum Ängströmii
Sphagnum recurvum
Sphagnum riparium
Sphagnum robustum
Sphagnum fimbriatum
Sphagnum plumulosum
Carex chordorrhiza
Carex tenuiflora
Carex canescens, var. *subloliacea*
Carex magellanica
Carex paludigams
Cicuta mackenziana
Chamaedaphne calyculata var. *angustifolia*
Galium tinctorium
Galium Brandegei

GLOSSARY

These definitions are intended only to clarify the words as used in this paper.

Aapamoor or **Aapasuo.** German and Finnish terms for the bogs of large area, chiefly treeless, that occur near treeline and are characteristically patterned with peat ridges.

Alluvial Lowland. Valley bottoms, of low relief, whose deposits are stream-borne sediments such as gravels, sands and silts.

Association. Plant species which grow together and are assumed to be unable to eliminate each other from the site. As used here, no uniform internal structure is intended such as society or community connotes.

Bar Lake. A pond or lake on the floodplain cut off from the river by deposition of a silt or sand bar as the stream migrates.

Base Level. A surface of such low slope that streams flowing across it cannot carry a load and further lower the surface by erosion.

Beaded Drainage. A stream that runs between successive enlargements such as lakes, ponds, marshes or bogs.

Bog. A vegetation-filled, water-soaked depression characterized by growth of mosses, chiefly sphagnum.

Bog Hollow. The wet, sedgy area between bog ridges. Where best developed they have at their center a mud-bottomed area with *Drepanocladus* and *Scorpidium* mosses and emergent sedges. See *flarke* in German and *Rimpi* in Finnish.

Bog Ridge. Ridge of peat moss supporting brush or trees and superimposed on a matrix usually of sedge meadow. The ridges are narrow and elongated usually across slope and may form into net patterns. See *Stränge* in German and *Pounut* in Finnish.

Braunmoor. German word for one of the bog types in the Cajander classification. This is a bog of calcareous influence, characterized by a mud bottom and certain species of *Drepanocladus* and *Scorpidium* and no sphagnum.

Bruchmoor. German word for one of the bogs in Cajander's classification. This is an acid bog where there is peat deposition, characterized by tall heath and birch shrubs and scattered trees, usually *Pinus silvestris.*

Depositional Slope. A constructional hillside or slope formed by deposition of coalescing alluvial fans or frost-moved materials from above. They usually are gentle slopes, intermediate between the lowlands and the bedrock hills.

Fen. A term used chiefly by Europeans for a grassy marsh. In England the term is usually reserved for reed marshes such as *Typha, Scirpus* or *Phragmites.* In Scandinavian writings it applies to any grassy marsh in contrast to a peaty or heath bog.

Flats. In Alaska, wet peaty alluvial lowlands of alternating areas of quaking bogs and Black Spruce forest; for example, the Yukon Flats, Tanana Flats, Nixon Fork Flats, Susitna Flats. This is a term borrowed from common usage and seems to correspond in Alaska to the Finnish *Aapasuo.*

Flarke. The German word for the wet, bog hollow between bog ridges. Ideally in a well developed *Strangmoor,* these at their center have a mud-bottomed area with *Drepanocladus* and *Scorpidium* mosses and emergent sedges. The term is applied to any wet sedgy area between bog ridges (called *Stränge* in German). See Bog Hollow and *Rimpi.*

Graded Slope. Slopes adjusted to the action of the erosion agent. Equivalent to slopes of mature topography in the Davis sense. Streams draining the graded slopes flow in smooth beds without falls or sudden changes of gradient. The minor streams have achieved adjustment to the master stream and the master stream to its local base level.

Hochmoor. German word for a raised bog, one which has grown above its site of origin, whose center is higher than the margins and whose surface is convex. Growth is by sphagnum proliferation and deposition of peat, water being supplied by rainfall or capillary action in the peat. There is usually one or several very acid ponds, *Kolke,* near the center and around the rim is a sedgy channel where water collects and flows away, the *Lagg.*

Indicator Species. Used in one of the European systems of classification; a species of plant restricted to certain physiological requirements. An indicator species is limited to and characteristic of a certain vegetation association and, for that reason. is used to define that association.

Kulju. Term equivalent to bog hollow, *rimpi* or *Flarke.* The wet, shallow water or sedgy hollow between bog ridges. This is referred to in Auer's paper without reference to the language.

Lagg. Swedish word for the channel around a raised bog. which carries away run-off.

Loess. Term taken into English geological usage from German which refers to wind-blown mineral deposits of silt sizes. pulverite. As originally defined the deposits will stand with vertical walls and contain land snails and have other limiting features, but the term in general use has become extended to include the more general meaning of wind-blown silt.

Mire. A term used in Scandinavian writings as equivalent to bog. It is taken, presumably, from their word *Myr.* In English writings this term refers to muddy morasses.

Moat. Term introduced in this paper for an area of water or coarse sedges in standing water at the margin of a bog which is actively advancing by thawing (Figure 22). Where the soligenous bogs responsible for thawing merge into bogs with more *Hochmoor* structure, the moat merges structurally and functionally into the *Lagg.*

Muck. Term used by placer miners in Alaska to refer to any fine-grained overburden over the gold-bearing gravels. In this paper the term is restricted to a generally accepted geological usage as a mixture of fine-grained mineral sediments and finely-divided organic material, usually frozen.

Muskeg. A swampy area usually moss-floored, characterized chiefly by an organic soil. Muskeg most often refers to a Black Spruce forest with a thick mat of mosses (Hypnaceae and sphagnum) underlain by peat, but can be used loosely to refer to a willow-grown sedgy low place, and in loosest terms is any wet lowland such as a slough or bog. The term is originally American Indian and is not equivalent to the Siberian *Taiga.*

Ombrogenous. Adjectival term indicating that the source of water for a bog is rainfall rather than stream-flow or the water table.

Oxbow. A lake, pond or slough on an alluvial lowland formed by cutting off of a stream meander by the migration of the stream.

Quaking Bog. A carpet of bog vegetation that is floating and sinks and quivers when walked on.

Palse. German word for an ice-centered hummock.

Paludification. Von Post's term for the formation and expansion of bogs by the rise of water table correlated with changes in drainage of growth of moisture-holding mosses. See swamping and *Versumpfung.*

Permafrost or **Perennially Frozen Ground.** Any ground remaining frozen over several years, in contrast to Annual Frost which thaws each summer.

Periglacial. Term referring loosely to events or areas near or under the influence of conditions of climate and geology controlled by an ice sheet.

Pingo. A mound formed by the growth of an ice lens in the soil. As the ice grows it heaves up and eventually bursts open the surface. These are larger than a *Palse* and may be several hundred yards long.

Primary Species. The species of plants which characterize an association of plants by their conspicuousness and by their being limited to that type of vegetation. A subjective term used in describing vegetation.

Pounu. The Finnish word for peat-, moss- or bog-ridge. These are ridges of sphagnum moss and other vegetation such as brush or trees superimposed on a matrix of sedges (usually). These ridges are narrow and elongated across-slope, string-like. They are the *Stränge* of German.

Raised Bog. *Hochmoor.* A bog that grows into a convex form, usually has several ponds in the center and is surrounded by a drainage canal.

Reisermoor. German word for a heath-birch shrub-covered bog in Cajander's classification.

Rimpi. Finnish word for the wet, bog hollow between bog ridges *(Pounu).* See *Flarke* and Bog Hollow.

Secondary Species. Species which occur singly or inconspicuously in a plant association and are not used to characterize it.

Solifluction. Movement of soil, usually restricted to movement due to processes in which freezing and thawing play a central part.

Soligenous. Adjectival term meaning that the source of water for a bog is percolating through it and carrying minerals.

Strang. German word for the string-like ridge of vegetation such as brush or trees growing on a mossy bog ridge on a bog surface. The ridges are narrow and usually elongated across slope; they may be in nets. These alternate with bog hollows which are sedge meadows or standing water with emergent sedges. See Bog Ridge, *Pounu.*

Strangmoor. A bog on whose surface are patterns, festoons or nets,

of vegetation growing on mossy ridges between which are patches of standing water or sedge meadows.

Structured (Structural) Soils. Soils with regular patterns resulting from the sorting of unconsolidated materials into accumulations of coarse and of fine particles or consisting of frost heaved patches or cracks. Sometmes the soil features are visible to the human eye and sometimes only expressed by the growth of plants, from the German *Strukturboden.*

Swamping. The process of expansion of bog vegetation at the expense of forest, correlated with accumulation of water in a lowland accompanying or as a result of the growth of moisture conserving mosses. See paludification and *Versumpfung.*

Thaw Slump. The process by which thawing and decrease in volume of frozen silt forms a depression into which soil and vegetation fall.

Topogenous. Adjectival term meaning that the source of water for a bog is the water table in a place where water has collected in a pre-existing depression.

Versumpfung. German word for the process of expansion of bog vegetation at the expense of forest, correlated with accumulation of water in a lowland accompanying or as a result of the growth of moisture conserving mosses. See Paludification and Swamping.

Weissmoor. The German word for a bog with a conspicuous development of sphagnum and sedges or low brush in Cajander's classification.

Yazoo Stream. Stream of deep water at the edge of a bog. The stream is formed by drainage and by the breaking of the carpet of vegetation when spring high water floats the bog mat. These are partially equivalent to the *Lagg* of Scandinavian *Hochmoors.* The standing water or coarse sedges in these marginal streams resemble the moat of thawing bogs but are of different physiographic origin.

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